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International Association for the Conservation of Geological Heritage

ProGEO SW Europe Regional Working Group

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ABSTRACT BOOK

ProGEO SW Europe Regional Working Group

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INVITED KEYNOTE

A renewed national inventory of geological heritage in Portugal

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Geoconservation has been a topic of discussion within the Portuguese geological community since the 1990s. One of the initial concerns in this debate was the absence of a national strategy for the protection of geological sites. In this context, particular emphasis was placed on the lack of an inventory of the country's geological heritage, which should be the first step in developing a national geoconservation strategy [1]. In the 2000s, two inventories were implemented to address this gap: the Geo-Sítios database of the current National Laboratory of Energy and Geology (LNEG, the Portuguese Geological Survey) [2] and the National Inventory of Geosites coordinated by the University of Minho [3].

The existence of two national inventories built with different methodologies, objectives, and assessment systems often led to ambiguity and confusion regarding their recognition by stakeholders (municipalities, environmental impact assessment and mineral exploration companies, universities, educators, and the general public). Many geosites were included in both inventories, while others appeared in only one, mainly due to methodological differences related to the assessment of geosite relevance and the overall territorial coverage.

The unification of these two databases was therefore essential for defining an objective national strategy supported by a single inventory to underpin geoconservation policies [4]. Hence, an initiative was recently launched by the two institutions (LNEG and the University of Minho) to merge their inventories and create a single national inventory of geosites, which is now available on the LNEG Geoportal: https://geoportal.lneg.pt/pt/bds/geossitios.

The methodology for merging the inventories involved analysing both databases to identify their differences and similarities, goals, organizational structures, data fields, and territorial coverage [5]. General characteristics of each inventory were maintained, such as the quantification of scientific value and vulnerability or the possibility to include sites of diverse relevance. Geosites in both databases were identified by comparing geological characterizations, associated bibliography, and interests. New data fields were added and modified to promote geosite management, including geosite delimitation.

The updated version of the Portuguese geological heritage inventory integrates therefore the main characteristics of its predecessor inventories: inclusion of geosites of national and international relevance—those with high scientific value; inclusion of other sites of geological interest with lower scientific value but possessing other types of relevance at regional or local levels; comprehensive coverage of the entire national territory, including the Azores and Madeira archipelagos; representation of all types of geodiversity elements, categorised by geological frameworks and types of geological heritage (lithological, mineralogical, geomorphological, palaeontological, etc.); possibility of cross-referencing with the various layers of the LNEG Geoportal, in particular with geological mapping; free access to data, which is made available with geographic information system (GIS) integration; and the possibility for users to submit proposals for new geosites through a dedicated form. Each geological framework is coordinated by three scientific experts, who are responsible for evaluating and delimiting both previously inventoried and newly proposed geosites.

The organization and online availability of data in a GIS environment enhance information access for nature conservation and land-use planning stakeholders, while also supporting the quantitative assessment of geosite value and vulnerability, as well as their spatial delimitation. These steps are crucial for guiding management strategies, including protection, promotion, and monitoring initiatives.

It is expected that this initiative will foster further efforts towards the conservation of Portugal's geological heritage, particularly in terms of the statutory designation of geosites that currently lack protection status. The existing legal framework, although allowing for the designation of geosites as protected areas, has proven unviable in its implementation. Therefore, close collaboration among the various organisations responsible for nature conservation will be essential in determining effective means and strategies for geoconservation.

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Geosites and Geoconservation: new descriptive and evaluation forms from Piemonte Region (Italy) for the Geoheritage management

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Geodiversity, known as the variety of the abiotic world [1], plays a crucial role in the environmental conservation, in the cultural heritage enhancement and in the sustainable development of the territories.
The Piemonte Region lies at the heart of the Western Alps, forming natural boundaries between Italy, France, and Switzerland.
Geologically, the Western Alps are an arc-shaped, double-verging orogenic belt characterized by a large variety of rocks that originated during a complex sequence of tectono-sedimentary processes through a time span of more than 300 My. For this reason, the Piemonte region is characterised by a high geodiversity.
The Western Alps three main structural domains can be recognized (Figure 1):
A) The internal sector, part of the Palaeo-Adriatic continental margin of the Liguria-Piemonte Ocean, contains continental polymetamorphic basement rocks, mantle derived rocks, and Mesozoic and Cenozoic sedimentary successions.
B) The axial sector includes metamorphic rocks derived from continental crust, portions of Mesozoic oceanic lithosphere, and relative Mesozoic sedimentary covers of the Liguria-Piemonte Ocean.
C) The external sector, part of the Palaeo-European continental margin of the Liguria-Piemonte Ocean, consists of continental crust units, locally intruded by Carboniferous-Permian magmatic rocks, covered by Mesozoic sedimentary successions and Cenozoic synorogenic deposits.
In the internal part of the Alpine chain Cenozoic and Quaternary synorogenic basins are present.
Tectonics vary across the range, with extensional, contractional, and strike-slip forces shaping the internal sector, while contractional kinematics dominate externally. The Italian flank is steeper than the outer slopes. Deep incised valleys (e.g. Aosta and Susa valleys) cut into the bedrock, shaped by Messinian erosion and Pleistocene glaciation, forming U-shaped valleys, moraines, and lakes. Holocene processes continue to modify the landscape.

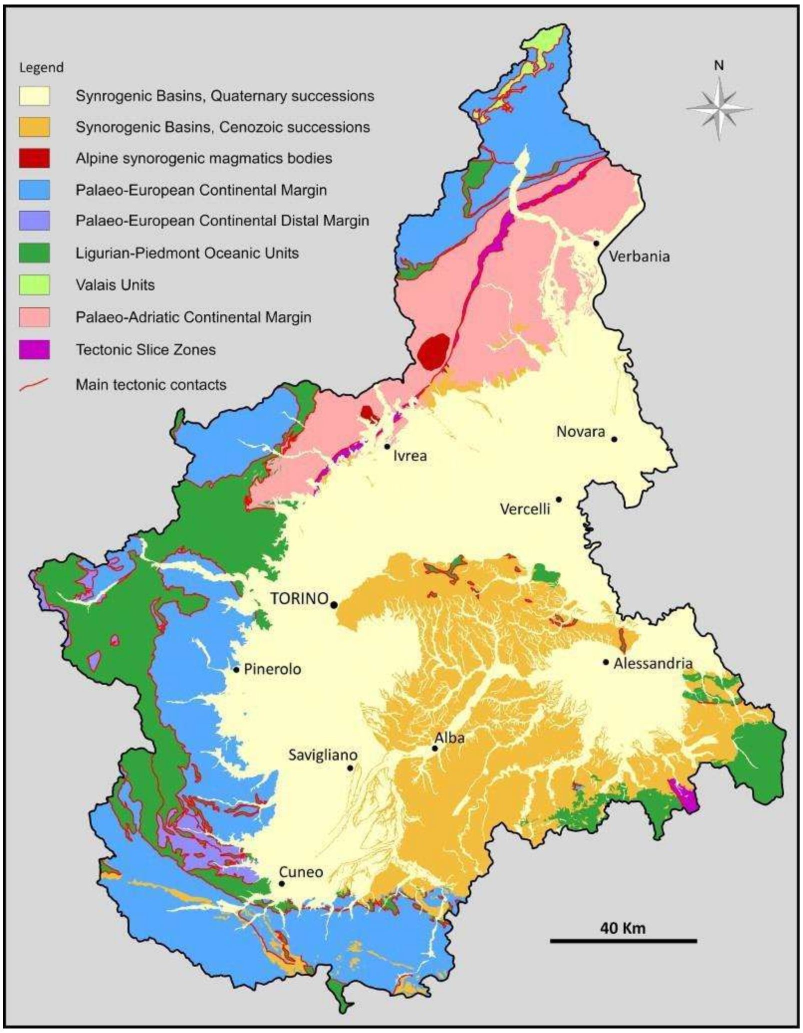

Figure 1. Simplified geological map of the Piemonte region (from [2]).

Referring to the general principle of Geodiversity and consideration of the regional geodiversity values, the Piemonte Region Council promulgated the Piemonte Regional Law n. 23/23 ("Provisions for the conservation, management and valorisation of the geological heritage") [3]. With this legislative measure, the public interest in geodiversity is recognised, geosites and UGGps are identified as geological elements of the territory with scientific recognition and particular scientific, cultural and landscape value (Figure 2); accordingly, the Law n. 23/23 promotes the conservation, enhancement of knowledge and management of geosites and geoparks. Hence, the ultimate aim of the regional law is the spreading of knowledge on geodiversity through a correct management of the regional geoheritage; this in turn can foster scientific, educational, cultural and touristic appreciation of geological sites and heritage for present and future generations.

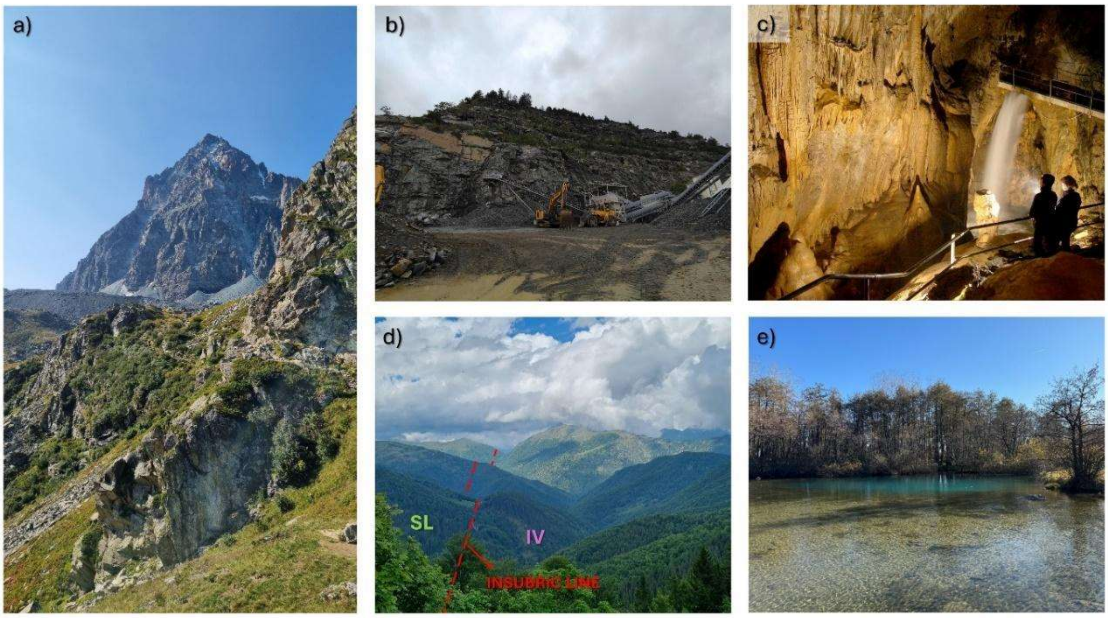

Figure 2. Examples of geosites in Piemonte Region: a) Monviso ophiolites; b) Mining site of mantle peridotites of Monti Pelati (Baldissero body); c) Bossea cave; d) Insubric Line at the Bocchetto Sessera (SL: Sesia Lanzo Zone; IV: Ivrea-Verbano Zone); e) Buried Spring at the Lake of Beinette (sources: authors).

In order to enhance interpretation of geodiversity and to perform correct management and conservation of geoheritage, a new integrative and descriptive form has been specifically designed for the regional geosites inventory and for the management of geosites, hence the local geoheritage. The geosite form was conceived in such a way to allow collection, revision, arrangement of data about Piemonte regional geosites coherently with scientific evidence about regional geodiversity, respecting both provisions for conservation, management and valorisation of geoheritage from the Piemonte Regional law n.23/23 [3] and directions from the Italian Institute for Environmental Protection and Research (ISPRA, in Italian: Istituto Superiore per la Protezione e la Ricerca Ambientale) for the National Inventory of Geosites.

In particular, the new form presents an ontology-driven design [4], understanding the needs of developing a sequential workflow, leading the user through six sections (Figure 3):

1. General Information aims at starting the collection of precise information, supporting data and providing contextualisation for the geosite, including general description, geographical framework, geosite typology and main characteristics, motivation of the choice of the geosite and territorial context.
2. Geodiversity elements of interest for the geosites, in which geological data collected from literature and field survey such as lithology, mineralogy, palaeontology, structures, geologic contacts, geomorphology, soils and hydrology, are classified and described in tables whose design is driven by semantic studies and ontological representation.
3. Scientific and contextual interests, including both primary and secondary scientific interests, according to the scopes proposed by the regional law; only one primary interest can be selected, while for secondary scientific and additional interests, there can be more than one choice; moreover, in this section the level of scientific importance is assessed.
4. Territorial and environmental dynamics, describing those elements that could make the geosite dangerous or vulnerable, including anthropic impacts.
5. Use of the geosite, in which information about accessibility and visibility of the geosite are collected, including local touristic services and facilities that could encourage fruition of the geosite, in a view of sustainable development of the territory.
6. Protection, conservation and valorisation, with this section useful for evaluating the state of conservation and the risk of degradation [5], allowing the formulation of suggestions for the management, including geosite protection, conservation and enhancement.

1. GENERAL INFORMATION

Date of Compilation					
Compiler			**e-mail**		
Surveyor			**e-mail**		
Name of Geosite				**Geosite ID**	
Data Acquisition	Bibliography		Field Survey		
Disclosable	Yes	No		Partially	
Location	**Province**	**Municipality**		**Locality**	

Latitude Point of view (WGS84)	**Longitude Point of view (WGS84)**	**Average altitude of Point of view**		
Latitude geosite (WGS84)	**Longitude geosite (WGS84)**	**Average altitude of geosite**	**Maximum altitude**	**Minimum altitude**

Form				**Dimension (order of magnitude)**		**Property**
Point	Linear	Areal	Mixed			
Type				**Exposure**		**Area**
Complex	Multiple	Single	System	Natural	Artificial	
Cartographic framing						
Iconography of the geosite						
Brief description and motivation of the geosite						
Shape file	Yes	No	**File name (.zip)**			
Land use (Corine Land Cover Level II):						
Subcategory (Corine Land Cover Level III):						
Subcategory (Land Cover Piemonte):						
Landscape-territorial context						

2. ELEMENTS OF GEODIVERISTY OF INTEREST FOR THE GEOSITE

LITHOSTRATIGRAPHY					
Geological domain and unit	**Lithology name**	**Lithology description**	**Genetic environment**	**Genetic process**	**Age of the process**
MINEROLOGY					
Mineral name	**Mineral description**				
PALEONTOLOGY					
Fossil name	**Fossil description**	**Genetic environment**	**Fossilisation type**	**Age**	
STRUCTURE					
Structure type	**Structure name**	**Structure description**	**Genetic environment**	**Genetic process**	**Age of the process**
Deformative					
Sedimentray					
Magmatic					
GEOLOGICAL BOUNDARY					
Type of geological boundary	**Geological boundary name**	**Description of the geological boundary**	**Age of the geological boundary**		
GEOMORPHOLOGY					
Geomorphological type	**Form name**	**Form description**	**Genetic environment**	**Genetic process**	**Age of the process**
SOIL					
Soil type	**Soil name**	**Soil description**	**Genetic environment**	**Genetic process**	**Age of the process**
HYDROGEOLOGY					
Hydrological body type	**Hydrological body name**	**Hydrological body description**	**Genetic environment**	**Genetic process**	**Age of the process**
NOTE: *Attach file (.doc/.docx/.pdf) with a brief descriptive text of the characteristics just described.*					

3. SCIENTIFIC INTEREST AND CONTEXTUAL INTERESTS

PRIMARY SCIENTIFIC INTEREST						
Scope 1	Physical geography	Geomorphological	Karst	Geopedological		
Scope 2	Mineralogical		Petrographic			
Scope 3	Structural geology	Geophysical	Geochemical	Volcanological		
Scope 4	Stratigraphic geology		Sedimentological			
Scope 5	Palaeontological					
Scope 6	Environmental geology	Hydrological	Hydrogeological	Glaciological		
Scope 7	Applied geology	Geomining	Geohistorical	Geo-economics	Geotouristic	
NOTE: *Detailed motivation of the discriminating factor with precise references to be visible objects in the geosite.*						
SECONDARY SCIENTIFIC INTEREST						
Scope 1	Physical geography	Geomorphological	Karst	Geopedological		
Scope 2	Mineralogical		Petrographic			
Scope 3	Structural geology	Geophysical	Geochemical	Volcanological		
Scope 4	Stratigraphic geology		Sedimentological			
Scope 5	Palaeontological					
Scope 6	Environmental geology	Hydrological	Hydrogeological	Glaciological		
Scope 7	Applied geology	Geomining	Geohistorical	Geo-economics	Geotouristic	
NOTE: *Detailed motivation of the discriminating factor with precise references to be visible objects in the geosite.*						
CONTEXTUAL INTEREST						
Scope 1	Artistic	Cultural	Historical	Archaeological	Architectural	Religious
Scope 2	Naturalistic	Landscape	Botanical	Faunal		
Scope 3	Educational		Public engagement			
Scope 4	Excursionistic		Sports			
Scope 5	Socioeconomic	Touristic	Food and wine			
NOTE: *Detailed motivation of the discriminating factor with precise references to be visible objects in the geosite.*						
DEGREE OF SCIENTIFIC INTEREST						
International	National	Regional	Local			
NOTE: *Known and recognized scientific value for International; for the others, elements of evaluation that may go beyond the geological context intervene.*						

4. ENVIRONMENTAL AND TERRITORIAL DYNAMICS

Description of hazards (natural instabilities)
Natural dynamic phenomena that can cause instability; natural processes that occur in the geosite area
Description of natural vulnerability
Consequences that the geosite may suffer as a result of potential and ongoing natural processes
Description of anthropogenic activities
Description of anthropogenic activities that may interfere with the preservation of the geosite
Description of anthropogenic impacts
What can effectively happen to the geosite as a result of anthropogenic activity
Suggestions for mitigation actions

5. USE OF THE GEOSITE

Accessibility				
Easy	Medium	Difficult	Impracticable unless with special permissions	Accessible to people with disability
NOTE:				
Site visibility from afar	Yes	No	Exclusively	
Position of the site	Submerged	Partially submerged	Emerged	
NOTE:				
Observation points				
Describe any observation points of the geosite that allow for the best appreciation of its characteristics				
Point of interest				
Describe any points of interest related to the geosite and present in the surrounding area				
Mode of access(*)/approach				
Private car	Horse/Mule	On foot		
Boat	Bicycle	Helicopter		
Cable car	Train	Bus		
Other:				
Services for users				
Scenic point	Equipped area (<1 km)	Campsite (<5 km)		
Point visible from a distance	Hotel facilities (<5 km)	Drinking water (<1 km)		
Parking	Catering (<5 km)	Other: *(specify)*		
Risks for use				
Describe what can happen when visiting the site both in terms of access and direct use				
Suggestions for mitigation actions				
Mitigation linked to risk of use				
Recommended season				
Winter	Spring	Summer	Autumn	

6. PROTECTION, CONSERVATION, AND SAFEGUARDING

Protected area			
Other territorial constraints			
Protection measures in place			
State of conservation			
Interpretation			
Good	Average	Bad	None
Risk of degradation			
High	Medium	Low	
Degradation factors			
Natural	Anthropogenic		
Need for conservation			
Necessary	Advisable	Superfluous	
Notes and comments			
Suggestions for enhancement			
Bibliographic references			
Insert bibliographic references, scientific publications, cartographic references related to the geosite			

Figure 3. New descriptive form designed for the Piemonte Region. The six sections are well defined.

Based on the art.5 (Level of Interest) of the Regional Law, an evaluation form has also been developed, in which criteria about the level of interest and values of the information from the descriptive form are evaluated with a different weight, for a total of 13 points (then normalised to 100):

1. Scientific value: this is the most important value to consider, with 4 points out of the 13; this criterion is defined on the basis of the conservation of the primary scientific phenomenon of the geosite (Integrity), on its rarity in the Piemonte Region (Rarity), on the representativeness of such phenomenon or process (Representativeness), on the scientific publications and recognition of the site from international organisations such IUGS, UNESCO, etc. (Scientific Importance).
2. Educational value: it refers to the example value from a scholar point of view, based also on the level of understanding and existent educational activities concerning the geosite (1 point).
3. Informative value: it refers to the attractive value from a touristic point of view, considering also informative publications, events and existent informative activities concerning the geosite (1 point).
4. Aesthetic value: it includes elements of visibility, points of view of the geosite, landscape relevance and potential disturbing elements (2 points).
5. Ecological value: it includes information about the surrounded environment and additional interests of the geosite; it indicates the presence of protected areas, SIC (Site of Community Interest, *Siti di Interesse Comunitario* in Italian) and ZPS (Special Protection Zone, *Zone di Protezione Speciale* in Italian) territories, but also the presence of flora and fauna of particular interest and other fundamental elements from biodiversity and geodiversity that provide biotic or abiotic ecosystem services (1 point).
6. Historical-Cultural value: it refers to information regarding additional interests such as history, culture, spirituality and art in all its forms (paints, literature, etc.) (1 point).
7. Accessibility value: in this section, level of accessibility, modality and time for reaching the geosite are evaluated, including information about accessibility for people with disabilities. (2 points).
8. Hazards-vulnerability-anthropic impacts value: this section includes an evaluation about the territorial and environmental dynamics (1 point).

The evaluation form allows to give a proper evaluation to each parameter of the geosite, indicating the strengths and weakness of each geosite, in order to: (i) select the site proposed as a geosite, and (ii) identify the elements that could be implemented for a better conservation, use and promotion of the geosite. Moreover, the evaluation form provides a useful tool for monitoring through the time the geosite itself, while doing the evaluation after a defined number of years.

In conclusion, the two forms provided by the research group offer an efficient and useful tool for collecting all the information required for a complete knowledge regarding a specific geosite (descriptive form), then use such information for identifies positive and negative elements of the geosite, in order to provide a correct management and conservation of the local geoheritage.

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Geoeducational programmes at the Grutas da Moeda, Portugal

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Caves are environments characterized by significant heterogeneity in terms of both geological and biological features which are referred to as geodiversity and biodiversity of the subterranean ecosystem. The biotic and abiotic characteristics of caves, together with the historical ones, are the cornerstones of their great scientific value (Sanna et al. 2023). The "Grutas da Moeda" (= Moeda Caves) are natural caves, located in Central Portugal (São Mamede Plateau 39°37'26.83"N; 8°42'18.49"W). This karstic region (Maciço Calcário Estremenho) is primarily composed by limestone deposits from the Middle Jurassic (Bathonian), more specifically the deposits of Serra de Aire Formation. The Grutas da Moeda cave, discovered in 1971, is one of the 17 show caves in Portugal (Brandão, 2009) and has been opened to visitors since 1974. Education is one of the major focus areas of geoheritage and geoconservation studies (Newsome and Dowling, 2018). The Grutas da Moeda cave has developed educational programmes adapted to the curriculum of preschool, primary and secondary education levels. The educational programmes and activities integrate geology with other fields like biology, chemistry, environmental science, history, and culture, thereby offering a holistic educational experience. These activities provide a wide range of interactive activities to enable students of all ages to enjoy nature and scenery of the caves, foster curiosity and love for learning, promote critical thinking, and deepen understanding of the cave's environment.

Figure 1. Students in the (A) movie room, (B) touring the cave, (C) observing limestone under the microscope.

Grutas da Moeda, in partnership with other entities such as Interpretation Center of the Battle of Aljubarrota, Alviela Living Science Center - Carsoscópio, Dinosaur Footprints of Serra de Aire developed combined activities as a way to promote multidisciplinary activities.

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A novel approach to assess the degradation risk for sustainable geotouristic exploitation of geosites: a case study from Beigua UNESCO Global Geopark

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Geoconservation in protected areas, as defined by the International Union for Conservation of Nature (IUCN), is the practice of conserving, enhancing, and promoting awareness of geodiversity and geoheritage [1]. In the twentieth century, in Europe, the conservation of geological heritage started to be considered in the decision-making process with the aim of conserving abiotic resources that have special value [2]. The process of geoconservation encompasses a variety of activities such as the identification of geosites, the evaluation of geodiversity and the assessment of potentialities and vulnerabilities of geosites, as well as the raising of awareness. Geotourism, together with geoeducation and geointerpretation, can be one of the effective tools to foster geoconservation [3] and it is fundamental to raise awareness and mainstream geoheritage to the general public. However, if not properly developed, geotourism can also be problematic, as it can expose geoheritage to considerable risk. An excessive flow of tourists without appropriate control and management strategies can lead to the degradation of the geosites, even causing permanent and irreparable damage. To avoid this, the formulation of a geotouristic strategy and the implementation of management actions on geosites are imperative.

The assessment of the degradation risk is an essential step in developing a geoconservation plan and establishing priorities in management. The identification and evaluation of threats to geoheritage was conducted using the *risk assessment matrix* considering the entire geopark territory and differentiating between the coastal and inland area due to their different intrinsic characteristics. Then, considering the existing methodologies and the relative criteria, a new method for the assessment of the degradation risk of geosites and their management for a geotouristic fruition has been developed and applied.

The risk assessment is crucial to comprehend the magnitude of the fragilities and vulnerabilities of geosites, as well as the tourism impact, allowing for the implementation of punctual management actions tailored to the unique features of each site. This method is designed to be closely linked to management actions and is therefore primarily aimed at protected area managers. The assessment is structured into three distinct areas, each representing a different area of management that requires a customized approach: i) the sensitivity (i.e., *the susceptibility or predisposition of a geosite to damage or destruction* according to Garcia-Ortiz et al. [4]) weighted according to the scientific value, ii) the visitors' pressure (i.e., the anthropogenic impact due to the influx of tourists to the site), and iii) the protection measures (i.e., the current strategies and infrastructure for mitigation). These three areas are evaluated through different criteria which have been chosen and integrated based on various existing methods. By evaluating geosites, it is possible to identify areas where geosites require actions and can facilitate a more precise management.

The method was implemented in ten geosites from the Beigua UNESCO Global Geopark (NW Italy) (Figure 1) that have a high touristic potential and that receive the highest number of visitors. The applied method allowed a comprehensive evaluation of the degradation risk and to identify the key management areas that necessitate intervention to safeguard geosites before using them as a tourist destination.

This method can be further supported by a preliminary assessment of the touristic potential of geosites, thereby serving as a valuable tool for territories that have not yet implemented a geotourism strategy and aspire to orient their efforts toward geotourism for the purpose of sustainable land development.

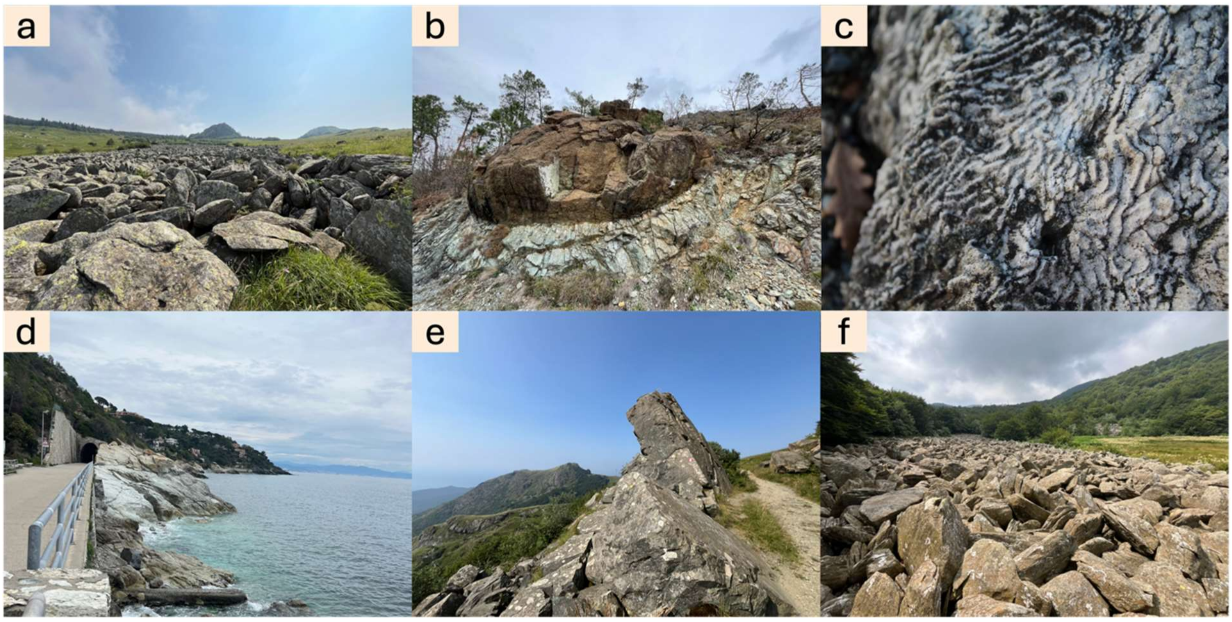

Figure 1. Examples of Beigua UGGp's geosites with high touristic potential. (a) *Pian del Fretto* blockfield, (b) *Lago dei Gulli* Peridotitic Spheroids, (c) *Ponte Prina* fossil corals, (d) Serpentinites and Metagabbros of *Lungomare Europa*, (e) *Pratorotondo* serpentinites, (f) *Torbiera del Laione* blockfield.

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Unveiling the Geoheritage of Gypsum Tumuli and Gypsum Tumuli Caves in the Spanish Sorbas Karst

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Eastern Almería in Spain offers a wealth of fascinating sites for geologists, including tectonic plate boundaries, faults, volcanic formations, and the remarkable gypsum karst of Sorbas. The Sorbas karst is one of the world's most renowned, particularly from a speleological perspective. It is primarily developed in the Yesares Formation, an alternating sequence of gypsum and marl deposited during the Messinian Salinity Crisis [1].
Karst in this region involves both subsurface and surface processes. Underground, marls are mainly eroded, and gypsum is dissolved, shaping extensive cave systems. At the surface, distinctive landforms such as various types of karst dolines (collapse and solution ones), karren features, gypsum tumuli (Fig. 1), and striking 30-meter-high gypsum scarps can be observed. The region is also home to numerous gypsum cave formations, including unique caves within tumuli, which feature rare gypsum speleothems, such as gypsum balls, hollow stalagmites, and gypsum "trees".
Cueva del Agua stands as the largest gypsum cave complex in Andalusia and the longest in Spain, with approximately 8 km of mapped galleries. The karst landscape also features over 1,000 cave entrances within a 12 km² area, while dolines provide striking examples of endokarst processes. There are a number of springs located on the edge of this karstic area, which are connected to a system of underground rivers.
This communication highlights the geoheritage significance of the Sorbas karst, with a particular focus on gypsum tumuli—one of its most distinctive landforms in this area. It aims to present an inventory of these features and explore their scientific and conservation value.
A gypsum tumulus (plural: tumuli) is a small, dome-like landform with an internal cavity, forming on weathered, bare gypsum rocks in arid and semi-arid climates or microclimates. Tumuli develop due to the upward doming of the uppermost gypsum layer, creating hemispherical mounds that can reach several meters in diameter.
Research on similar landforms in the Ebro Basin, Sicily, and the Bologna area suggests that gypsum tumuli form through a process of dissolution and reprecipitation of gypsum [3]. Rainwater percolates through pore spaces in gypsum beds commonly composed of large selenite crystals, dissolving calcium sulphate, while evaporation leads to supersaturation and subsequent gypsum crystallization in inter- and intracrystalline spaces. Some authors propose that crystallization of this secondary gypsum generates growth pressure, contributing to the volume increase and formation of the dome-like shape.
Based on current state of knowledge, gypsum tumuli exhibit an elliptical plan-view shape, reaching height up to 1.35 m and long up to 15 m are rarely reported in literature. An inner cavity presents usually a size that varies from a few centimetres to a maximum 1.00 m in the Sorbas plateau [5]. The large cavities are relatively rare.

Figure 1. Gypsum tumuli in the gypsum plateau near Sorbas town (Almeria, Spain); A – general view of the plateau with visible Messinian gypsum outcrops (arrow indicates some gypsum tumuli); B – the Monika Cave (author, M.C. is on the photo); C – the Cone Cave (author, A.J. is on the photo testing this accessibility to adult person); D – inner space of the Monika Cave; E – speleothems on the ceiling of one of the cavities.

Our inventory works were realized in the gypsum plateau, in a place where gypsum tumuli were studied and first defined by Pulido-Bosch [6]. It took two expeditions of 10 days each to get to the top of the gypsum plateau near Sorbas town in 2016 at the beginning of November, and in April 2023. We documented gypsum tumuli using multiple methods, including measuring by tapes, laser rangefinders, geological compass, GPS, photography, photogrammetry, and petrographic observations. We applied aerial and terrestrial photogrammetry to document the most prominent areas of the tumuli outcrops. During expeditions, observations and measurements of tumuli landforms and their inner cavities inherent with detached rock were made.

Over the few kilometres long gypsum plateau we documented about 300 tumuli landforms both grouped in numerous clusters and occurring individually. There is a limit to the size of the tumuli - they seldom exceed 4.0 m horizontally and 0.5 m in height above the surrounding terrain. Their shape in plan is relatively constant regardless of their size, ranging from circular to elliptical. It is estimated that up to ca 60% of an entire detached gypsum layer is destroyed as a result of erosion processes. Our study reveals the presence of cavities inside gypsum tumuli with sizes enabling an adult person to crawl inside, and which therefore can be called caves. The largest one is the Desert Cave according to the true length and height of the chamber, but according to planar dimensions it is the Monika Cave (Fig. 1B, D; Tab. 1). The opening to the inner cavity is generally on the marginal part of the tumuli and rarely in the middle top creating a crater-like opening (Fig. 1C). Inside the cavities there are various gypsum speleothems on the ceiling and sometimes also on the bottom (Fig. 1E).

Name of the cave	True length [m]	True width [m]	Height of the chamber [m]	Width × height [m] of proper entrances*	GPS coordinates
Echo Cave	3.62	1.82	0.40	0.55 (crater entrance)**	2.0397955°W 37.1107229°N
Luna Cave	5.00	4.46	0.67	3.45×0.67	2.0402734°W 37.1115593°N
Desert Cave	6.96	2.80	1.00	5.20×0.94	2.0422331°W 37.1101030°N
Cone Cave	2.93	2.79	0.48	1.04 (crater entrance)**	2.0518365°W 37.1163260°N
Arcadia Cave	3.22	1.36	0.45	1.25×0.45	2.0518464°W 37.1164710°N
Sentinel Cave	2.68	2.50	0.34	1.80×0.42	2.0540590°W 37.1194076°N
Monika Cave	6.19	5.01	0.85	1.60 (crater entrance)**	2.0516944°W 37.1028250°N
Hermit's Cave	2.90	2.20	0.50	1.35×0.48	2.0548485°W 37.1189069°N
Solis Cave	3.33	3.17	0.50	1.30×0.50	2.0550653°W 37.1190544°N
Lone Cave	2.80	2.60	0.36	1.25×0.36	2.0520028°W 37.1245722°N
Turtle Cave	3.80	2.90	0.40	0.42×0.36	2.0612361°W 37.1000444°N

Table 1. The gypsum tumulus caves documented in the Sorbas karst area; * - A proper cave entrance is one that allows an adult person to crawl inside it [7]; **- crater entrance has only width measurement.

Protecting the gypsum karst of Sorbas should be a top priority for environmental management due to its diverse surface and subsurface geomorphological features [1]. The significance and vulnerability of this area were recognized when a conservation effort was first implemented in 1989. However, only 2,375 hectares of the gypsum karst were designated as protected under the designation of the "Paraje Natural de Karst en Yesos de Sorbas", leaving much of the landscape still exposed to potential threats.

Local efforts have played a crucial role in safeguarding the site. The regional speleological club has contributed significantly to conservation, particularly through the introduction of guided cave tours. This initiative not only raises awareness but also provides financial incentives for local communities to support sustainable tourism over more destructive land uses.

Despite these efforts, gypsum quarrying remains a major challenge. Sanna [8] highlights the environmental impact of quarrying in Sorbas, stressing the need for a balanced approach that allows resource extraction while preserving the karst ecosystem. The issue of karst protection is not unique to Sorbas. For instance, the South Harz gypsum karst in Germany has adopted the guidelines for Cave and Karst Protection to mitigate human-induced damage. In contrast, the Pisky site in Ukraine suffered significant destruction due to quarrying, illustrating the severe consequences of the lack of or inadequate conservation policies.

The karst environment is a key component of geodiversity, encompassing a range of geological, geomorphological, and hydrological features that enhance a region's scientific and aesthetic value. Sites with significant abiotic features require dedicated conservation measures to protect their unique characteristics. Establishing geoparks could be one strategy to strengthen legal protection and promote sustainable tourism. Identifying and characterizing such sites is a fundamental step in any geoconservation strategy [9].

However, geotourism must be carefully managed. Creating detailed maps and inventories of geoheritage sites is essential for understanding the spatial development of landforms. While encouraging visits to karst landscapes provides educational and economic benefits, poorly planned access routes and infrastructure can lead to degradation. Effective conservation efforts should include educational outreach, ensuring that protected sites are presented in an engaging and accessible way for the public.

Promoting gypsum tumuli and the unique gypsum tumuli caves—one of the most distinctive landforms of gypsum karst—can enhance the geotourism appeal of Sorbas and similar locations. Increased visibility through social media and other outreach platforms can help foster greater appreciation and awareness of these unique geological formations, ultimately contributing to their long-term protection.

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A Geosite of My Own

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UNESCO Global Geoparks are territories where rocks and landforms help us to understand the dynamics of planet Earth and where geology is used as a lever to promote the sustainable development of these territories. Through a holistic strategy, they are one of the most important territorial-based strategies of the 21st century. As such, aware of the scientific, educational and cultural value of this territory, work for the application of Estrela to become a UNESCO Global Geopark began in 2014, leading to the formalization of the application in 2017, its approval by the Global Geoparks Council in 2019, and the official ratification by UNESCO in July of 2020. This moment marked a historic moment for the valorisation of the natural heritage and the people of this territory, the highest mountain in mainland Portugal.

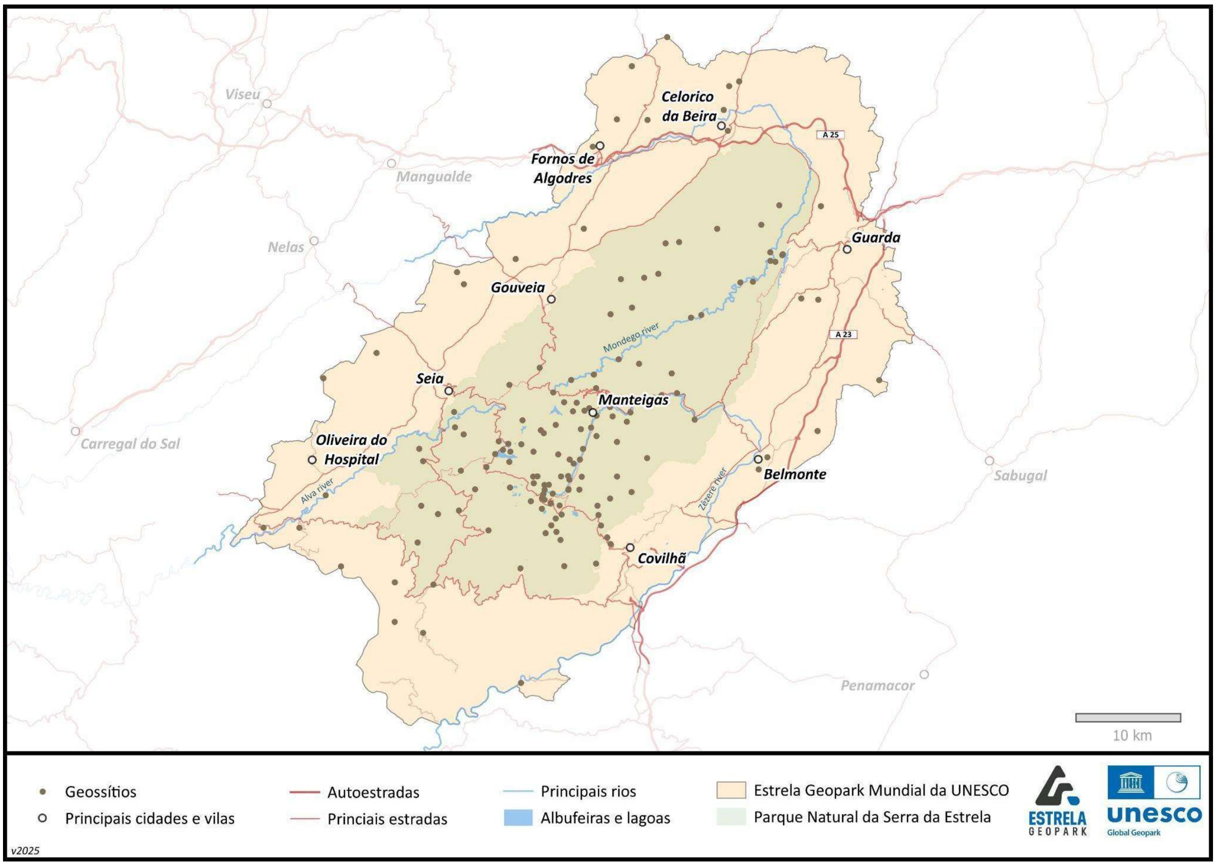

Figure 1. Map of the Estrela UGGp.

The basis for this classification as a UGGp is, as mentioned, its geoheritage. In the case of the Estrela UGGp, its geosites include locations with scientific, touristic and educational relevance which facilitate understanding the different processes that have transformed the landscape of the mountain we know today. In particular, the landforms left by ancient glaciers are intrinsically related to the heritage of this mountain, with 3 geosites of international scientific relevance present in this territory. However, concerning the approach of a UGGp towards its geosites (Figure 2), should take into account not only their geology, but also encompass the relation between geology and the surrounding biodiversity and history of human occupation, which creates a holistic approach towards the unique heritage of these designated territories.

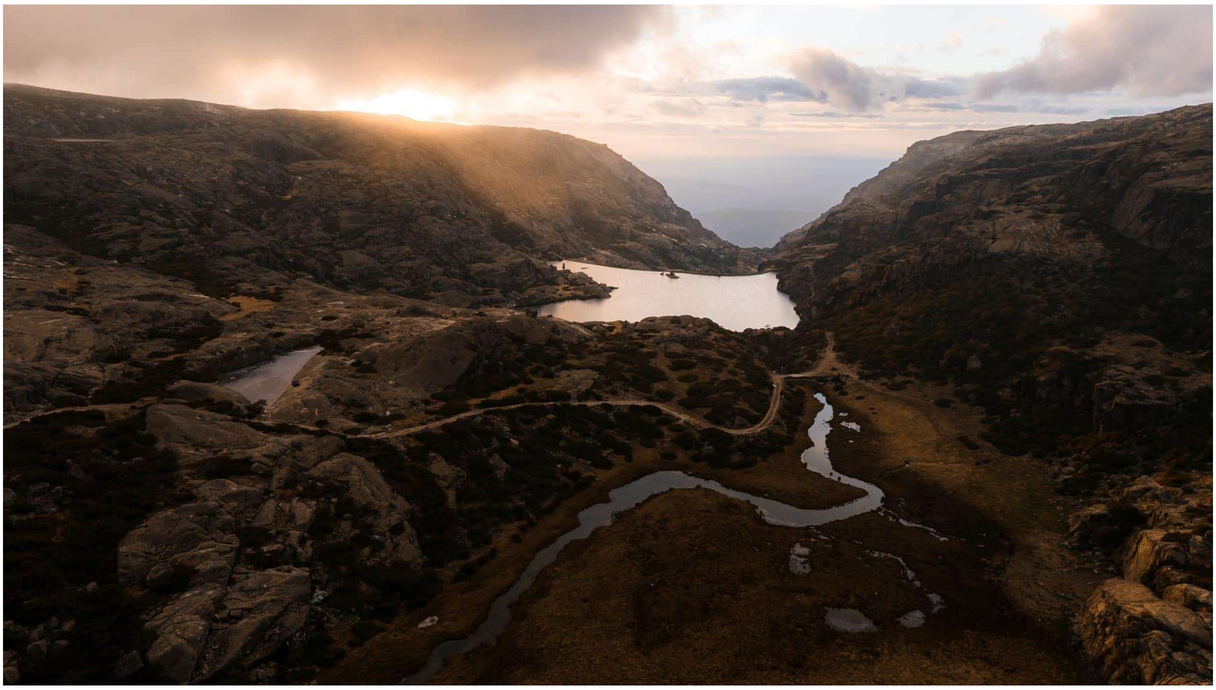
Figure 2. Loriga glacial valley.

Monitoring strategies are fundamental for the management and conservation of geological heritage, allowing for the tracking of its evolution over time. They are also essential for understanding the factors, whether natural or anthropogenic, that may threaten the sustainability of these sites [1]. Furthermore, fostering a sense of belonging and raising awareness towards geodiversity and geoheritage has historically been a challenge, as their narratives deal with more abstract concepts and temporal scales much distant from the daily lives of populations. This difficulty ultimately reflects a greater risk of degradation, including vandalism. In this context, citizen science emerges as an effective solution, helping to address gaps in the supervision of geosites. Although this approach requires investment, it proves to be economically viable, particularly when compared to methods that do not involve public participation, such as hiring dedicated teams exclusively for site monitoring. Moreover, considering the results achieved by these projects, it represents a sustainable long-term investment [2,3].

With this in mind, the Estrela UGGp created the project "A Geosite of my own", which, through a threefold approach with interconnected components, aims at promoting geoconservation and the integration of the community in the conservation strategy (Figure 3).

Figure 3. Educational activities are focused on students, teachers and the local communities.

The main actions to be implemented are: i) to assess, in a pilot approach, the conservation status of some of the geosites of the Estrela UGGp and the ecosystem services they provide; ii) To raise awareness among school-age youth about geodiversity, as well as the ecosystem services it provides, and the importance of preserving and sustainably using these values; iii) To develop, for this purpose, innovative technological tools that contributes to the preservation of the natural heritage of the territory. This initiative, due to its innovative nature, integrated the list of *UNESCO abrdn Projects*, which contributed profoundly for its implementation and which, through the support of UNESCO, will be able to implement incisive actions in the territory of Estrela. This innovative approach will start as a pilot project capable of expanding within the Estrela UGGp territory but also capable of being replicated in other UGGps all over the world.

To summarize, geoheritage is the basis for a UNESCO Global Geopark, and the promotion of initiatives that foster the involvement of the community in the protection of their heritage is of crucial importance. Through the implementation of the "A Geosite of My Own" project, an important step will be taken to enhance and preserve the unique values of this territory that constitutes a chapter in the book that is the story of planet Earth.

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Sustainable management and protection of a Late Albian-Cenomanian dinosaur tracksite from Mosqueruela (Maestrazgo UNESCO Global Geopark, Teruel, Spain)

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The Late Albian-Cenomanian Cretaceous `Mas de Pérez´ tracksite is located at the Aragonese branch of the Iberian Mountain Range (Fig. 1a), in the northeastern Spain municipality of Mosqueruela (Teruel) (Fig. 1b), within the boundaries of the Maestrazgo Cultural Park, UNESCO Global Geopark (UGGp). The site lies in the `Place of Community Interest' area (Spanish LIC: Lugar de Interés Comunitario) of `Maestrazgo and Sierra de Gúdar', on land forming part of the Natura 2000 Network (ES2420126). The ichno-assemblage occurs in the limestones and marls of Mosqueruela Formation and comprises around 110 tracks assigned mostly to theropods.
The layer containing the tracks is on the upper part of a carbonate massif on a planation surface toponymically known as ´Pinar Ciego´ (the spanish name means `blind pinewood´ for the high density of the pine forest). The ichnites are at the top of a subhorizontal limestone stratum, included in the lower part of the limestones and marls of the Mosqueruela Formation (laterally equivalent to the Aras de Alpuente Fm), at circa 1600 m a.s.l. in the central Maestrazgo-Bajo Aragón sub-tabular area [2] of the east central Iberian Chain. This lithostratigraphic unit is limited at its base by the upper terms of the Utrillas Fm, Late Albian in age of continental fluvial-coastal origin in the study area, and on top by the Barranco de los Degollados Fm, which is Turonian in age and composed of progressively deeper carbonate marine platform deposits as it ascends in the lithological series. In the studied area of Mosqueruela, the materials were deposited during the Late Albian–Cenomanian, a time interval that marks the beginning of the largest marine transgression recorded on the planet and led to the flooding of continental coastal zones and the development of extensive shallow marine depositional environments.
The Cretaceous continental vertebrate record of Europe is particularly patchy, with a remarkable gap corresponding to the first half of the Late Cretaceous [1]. Until recently, a few isolated fossil tracks of continental taxa were known from the Cenomanian of the Iberian Peninsula. This marked early Late Cretaceous faunal gap is a consequence of the substantial reduction in emergent land areas that began in the late Albian–Cenomanian with a major sea-level rise that transformed Europe into an island archipelago. A great number of the known Cenomanian fossils are dinosaur footprints preserved in tidal and littoral deposits [1].
In the Iberian Mountain Range was reported the presence of large sized theropod footprints [4], not arranged in trackways, in limestones and marls of Mosqueruela Formation at `Abenfigo´ tracksite (Castellote, Teruel, Spain). This site was declared as an Asset of Cultural Interest with the category of Paleontological Zone. In the same province and geological formation, was firstly reported [3] the presence of about ten theropod tracks in `Mas de Pérez´, the site on which the present work is focused. In 2022, `Mas de Pérez´ presented a clear evident risk of deterioration. In addition to being exposed to severe atmospheric and biological agents, the surface with footprints was located on a forest path. The proximity to the municipality and the density of motor vehicles, especially during the mushroom season, made the site highly vulnerable. Thus, urgent preventive measures were considered to ensure its stability, such as the diversion of traffic by an alternative road. This demand was communicated to the Town Council of Mosqueruela and the private owners of the property where the track site is.

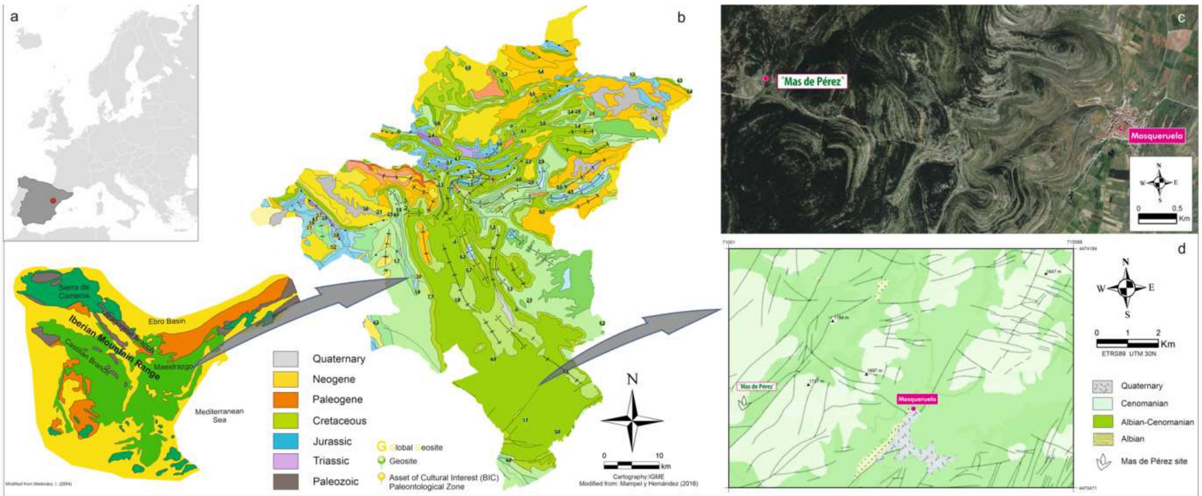

Figure 1. Geographical (a, c) and geological location (b, d) of "Mas de Pérez" dinosaur tracksite (Late Albian-Cenomanian) in Mosqueruela (Teruel, Maestrazgo UNESCO Global Geopark, Spain).

This was the starting point of a paleontological action plan to dig the site and to survey equivalent outcrops in the area, in order to complete the scarce ichnological record of the Cenomanian at the Iberian Peninsula.

After the first paleontological excavation carried out during 2023, one of the trackways increased from 3 consecutive ichnites to 20. Furthermore, new isolated tracks were found, reaching a total of 30 at the end of that campaign. In addition to the strictly paleontological work carried out, a 6.4 km long georoute was designed in 2023, with the starting point at the tourist office of Mosqueruela. Along the route, directional signs and information were installed to reach the site, as well as a rope and post fence around the paleontological site (Fig. 3d). The informative panels were placed, avoiding visual contamination, on pine trees that served as column base. Since then, the information to facilitate the interpretation of this site is available in Spanish and English through a QR code. During the 2024 excavation campaign, the site was enlarged by more than 100 square meters and new tracks were discovered, increasing the total number to 110 (figure 2b) on a surface near 300 m^2.

This track-bearing surface, affected by a network of orthogonal joints, is composed of a wackestone with bioclasts and desiccation cracks, which were deposited in a shallow shelf environment open to the Tethys with subaerial exposure events. Currently there are six theropod trackways as well as some isolated trydactil footprints that sum a total of 99 tracks and 11 undetermined shallow long depressions (Fig 2b. inset: MS1-72). Therefore, the ichno-assemblage comprises 110 tracks assigned mostly to theropods (figure 2b).

Currently the largest tridactyl trackway is composed of 24 consecutive ichnites and it is attributed to a mid-sized bipedal dinosaur. The tracks length ranges from 0.21 to 0.27 m with an average of 0.23 m. All the footprints in that trackway are tridactyl and mesaxonic, and are shallow due largely to the erosion suffered. The digit III (average of 0.22 m length), is longer than the other two (digits II and IV), both sub-equals in length with an average of 0.16 m in length. Digit III is sigmoid and slightly wider midway along its length than proximally. The end of the digital print is triangular and pointed, but without a separated claw mark (figure 2b inset: T1MS1-6). All tracks are elongated (FL/FW relation average of 1.41), with slender digits occasionally with clear pad impressions and claw marks.

It is also noticeable that near the ´Mas de Pérez´ and in the same Mosqueruela Fm, was located an *ex-situ* new fossil plant assemblage, containing two types of gymnosperms, composed of large multibranched coniferous axes of the genus *Frenelopsis* and a very complete leaf of the genus *Desmiophyllum* [5], as well as other desubicated site with remains of fishes.

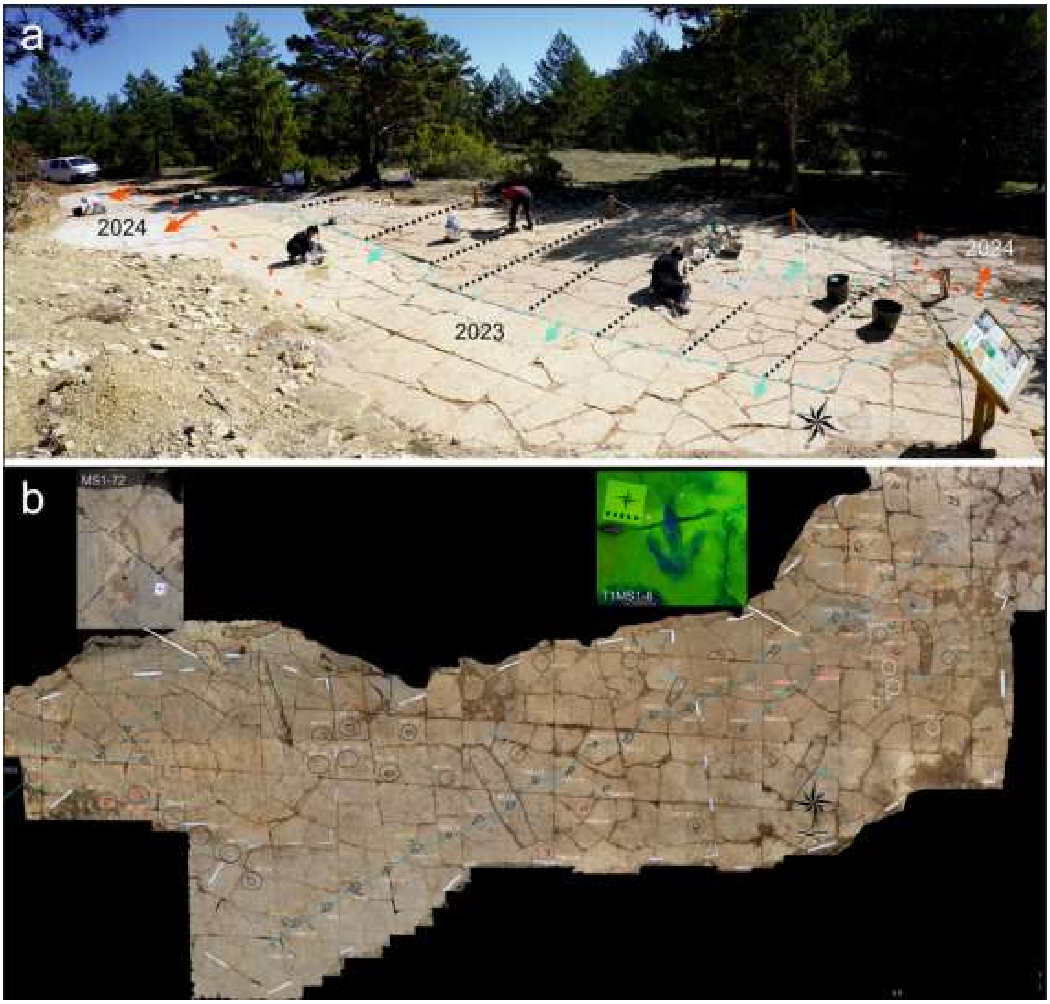

Figure 2. a) Field data were carried out in two excavation and conservation actions developed during 2023 and 2024. b) A three dimensional model was used in order to provide a more objective representation of tracks and all original specimens remain in the Geopark.

Throughout this project, a series of initiatives related to the dissemination of the paleontological site have also been carried out by Fundación Dinópolis. During the summer of 2023, more than 200 people participated in an Open Day at the site (Fig. 3c), and in 2024, the entire educational community of the municipality (more than 60 people) were able to visit the site accompanied by paleontologists during the Maestrazgo UGGp Week (Fig. 3b). Previously, different educational activities had already been carried out by paleontologists for all students in the municipality's own educational centre (Fig 3a), where children had the opportunity to review some paleontological concepts. Throughout 2024, in the framework of Mosqueruela's Summer Cultural Week, two educational workshops were also organized for all audiences with the aim of sharing the main paleontological advances and challenges with the local society. Since 2023, numerous media (press, radio, TV) and social networks have focused their attention on this paleontological site.
Another milestone, with the aim of educating and disseminating paleontology to the general public, was to publish the *Paleoguía* titled '*Dinosaur tracks in Mosqueruela'*, which compiles in a scientifically-rigorously but friendly language for all audiences, resources of the municipality related to its geoheritage with focus in ´Mas de Pérez´ tracksite (Fig. 3e). This publication is available for free online download and the -free of charge- printed edition is also available at information points, such as the Tourist Office of Mosqueruela.

Figure 3. Some of the paleontological knowledge dissemination actions undertaken at Mosqueruela municipality: a) Workshops for schoolchildren at school and b) activities for the educational community at "Mas de Pérez" paleontological site. c) Open Day for visitors in this dinosaur tracksite with palaeontologist of Fundación Dinópoolis. d) Interpretive panels at the paleontological site available in Spanish and English and e) Cover of *Paleoguía* 05 publication which deals about the geotourism resources of the municipality (available online and printed though tourism offices).

´Mas de Pérez´ track site contributes to covering the remarkable gap corresponding to the first half of the Late Cretaceous epoch that was, until recently, almost completely devoid of significant fossil occurrences in Iberia. But thanks to this new dinosaur site too, Mosqueruela houses a geological heritage that through a collaborative paleontological LEADER Projects, points as relevance and can be used for geotourism initiatives and the basis for sustainable socio-economic development of the municipality.

Acknowledgements

This research was funded by the Gobierno de Aragón (Spain) through the Research Group E04_23R FOCONTUR, Instituto Aragonés de Fomento, LEADER projects (Maestrazgo Unesco Global Geopark, Asociación de Desarrollo Gúdar – Javalambre y Maestrazgo –AGUJAMA- and Ayuntamiento de Mosqueruela), as well as Unidad de Paleontología de Teruel (Ministerio de Ciencia, Innovación y Universidades, Gobierno de España). We are grateful to the colleagues from the Fundación Conjunto Paleontológico de Teruel-Dinopolis for their support and to Jerónimo Gargallo, the person to whom the ichnites first attracted attention.

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Geological heritage and conservation challenges in Andorra

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Geographical and geological setting

Andorra is a small, mountainous country covering approximately 470 km^2 in the central Pyrenees. The average altitude is about 1.900 m.a.s.l., with values ranging from 840 m to 2.942 m, and with 65 summits more than 2.500 m high. The Pyrenees are an Alpine orogen in southwestern Europe, straddling the border between France and Spain (Figure 1). The Pyrenees were originated by the convergence between Iberian and Eurasian plates from Late Cretaceous to early Miocene [1]. The Alpine deformation gave rise to E–W trending thrust sheets, some of which involved basement Neoproterozoic and Paleozoic rocks, forming an antiformal stack, which constitutes the so-called Axial Zone.

The country is carved by two main rivers and its corresponding valleys: Valira del Nord in the west and Valira d'Orient in the east. These two rivers converge in Andorra la Vella to form the Valira river.

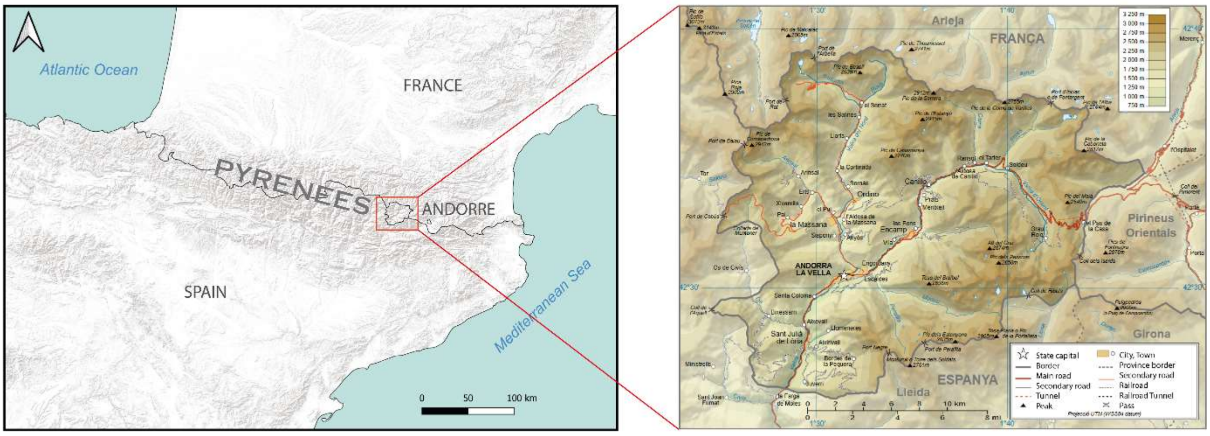

Figure 1. Location of Andorra in the Central Pyrenees.

Demographic and economic context of Andorra

The population is about 87.000 inhabitants, that gives a population density in the country of about 185 inhabitants/ km^2 [2], which are concentrated mainly in the valley bottom.

There are three main alpine ski resorts that occupy 30,75 km^2 (6,6% of its territory). In the 2023-2024 season, 2.2 million ski passes were sold [3], which makes the ski industry one of the main sources of income for the country. In this sense, Andorra is under significant urban and tourist pressure that could put at risk the preservation of the natural environment.

Protection of the natural environment in Andorra

In this context, in the early 2000's three protected natural areas were created in the country: the Sorteny Valley Natural Park (SVNP, 2003), with a total of 1,080 ha; the Comapedrosa Valleys Natural Park (CVNP, 2003), with a total of 1,542 ha; and the Madriu-Perafita-Claror Valley (MPCV, 2004), with a total area of 4,247 ha, the latter declared a World Heritage Site by UNESCO in the category of Intangible Cultural Heritage. Moreover, the entire Parish of Ordino was declared a UNESCO Biosphere Reserve in 2020.

One of the main objectives established by the decrees for the creation of the natural parks is to protect the unique character and integrity of the natural values of geological heritage, vegetation, wildlife, the water system, the atmosphere, and the landscape.

Regarding natural parks, the protection regime is regulated at the national level by Law 7/2019, of February 7th, on the conservation of the natural environment, biodiversity, and landscape. This law includes the protective nature of representative natural systems or elements of particular interest due to their fragility, uniqueness, landscape value, scientific significance, or ecological and geological interest. The law states that "Natural protected areas are considered the zones of the territory of the Principality of Andorra that contain representative, unique, fragile natural systems or elements, or those of special ecological, scientific, landscape, or geological interest, and are declared as such in accordance with this Law"; as well as “It is prohibited to destroy, alter, or degrade places of geological interest, as well as collect fossils and minerals, even in natural or artificial underground cavities". However, the law does not specify which are the geological interest sites, nor does it foresee their declaration.

Furthermore, Andorra has had a protected flora regulation since 2021 and a protected fauna regulation since 2024. There is also the National Landscape Strategy of Andorra 2035, and the National Biodiversity Strategy of Andorra. All these laws and regulations include inventories that always referred to flora and fauna, but in any case they include an inventory of geological interest sites.

On the other hand, Law 9/2003, of December 19th on the Cultural Heritage of Andorra, establishes measures for the protection, conservation, and dissemination of cultural heritage, including paleontological heritage, and provides for the creation of specific inventories to identify and preserve sites of paleontological interest. In this context, in 2006 the "Inventory of the Paleontological Heritage of the Principality of Andorra" [4] was presented. In this work, 16 outcrops were defined based on bibliographical information and field validation; and it included an assessment of the sites along with a proposal for protection. Based on this inventory, areas of paleontological presumption (EPP) were defined, which include a buffer area around the outcrops. A revision of the 2006 inventory was carried out in 2021 [5]. There is no evidence that the cartography of EPPs has been updated.

Within the framework of this law, when any construction work affects an EPP, authorization from the Department of Cultural Heritage is required to proceed. This department requests an expert report to assess whether to authorize the work or not, or if a modification of the construction plan is requested. Moreover, if during the execution of any type of construction work, paleontological remains are discovered, the site manager is required to halt the work and notify the Ministry responsible for Culture, which must assess the significance of the finding.

Case study: assessing the impact of a ski resort expansion on a paleontological site

In 2023, a potential impact on an EPP was identified due to a project for the development of a new ski area in the Pal-Arinsal ski resort. This project included the construction of new slopes, chairlifts, access roads, water catchment areas, water storage ponds, etc. In response, the Department of Cultural Heritage consulted external geologists—specifically, the team responsible for the 2021 inventory update—to evaluate the potential impact on the EPP.

The area of interest corresponds to the Port Negre peak (Arinsal), one of the zones classified as of special interest in the 2021 inventory, where around twenty outcrops were identified. The area is formed by Silurian rocks (black shales and limestones) and Lower Devonian rocks (Rueda Formation, formed by grey shales and grey and brown limestones). The fossil content is rich, including remains of cephalopods (orthocerids and onchocerids), crinoids, gastropods and brachiopods (Figure 2).

To conduct the assessment and expert analysis, a field survey was carried out, with a particular focus on the location of the chairlift pylons, as these structures appeared to pose the greatest risk to the EPP. The study included detailed geological mapping, site prospecting, the collection of macrofossils, and the sampling of materials for subsequent micropaleontological analysis.

The final report recommended the designation of two protection and conservation areas due to the site's geological significance. Of particular significance is the site's well-preserved Silurian-Devonian transition, characterized by a sedimentary, original and gradual contact.

Conclusions

The case of Andorra underscores the delicate balance between economic development and the preservation of geological heritage. While some regulations exist, their implementation and enforcement remain a challenge. Strengthening conservation measures, promoting awareness, and incorporating geological heritage into broader environmental policies will be crucial steps toward ensuring the protection of these invaluable sites for future generations.

Figure 2. Fossils in Port Negre peak. Left: crinoids. Right: orthocerids.

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Climbing crags: an unusual approach for science outreach in the frame of the CARG project

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In the Central Alps, the connection between man and mountain has always been an integral part of the culture of local populations. In the past decades the mountainous area of Valchiavenna, Val Masino and Alto Lario has evolved from a place where the main means of subsistence were mountain pastures and woods, into a territory where sports tourism, such as trekking, skiing, alpinism and climbing, has become an important source of income.
From the early 1900's, when mountaineering was an elitist activity, numerous alpine associations have been established, like the Italian Alpine Club (CAI), giving rise to the clustering of alpinists and climbers in large and lively communities. In the 1960's, Val di Mello (Val Masino) was one of the first places in Italy where the climbing movement known as 'Nuovo Mattino' took place. This new fundamental climbing philosophy broke away from classic climbing, that involved extensive use of artificial aids (such as nails, fixed ropes, etc.), definitely embracing the technical difficulty of free-climbing. Nowadays, climbing has become a mainstream sport, and territorial alpine associations provide means and best practices to mountaineers for carefully facing the mountain. Although climbers have the possibility to "put their hands on the rock", in most cases they are unaware of the surroundings, even if the geological features could affect the climbing style.
In the last years, a geological survey has been conducted in the mountainous region of Valchiavenna, Val Masino and Alto Lario, in the frame of the CARG Project (Carta Geologica d'Italia alla scala 1:50.000, geological sheets 038 "Chiavenna", 021 "Passo dello Spluga", 022 "Madesimo", 037 "Bodengo"). The study area is located in the north-western Central Alps, just South of the Italy-Switzerland national border. Here, we can find different poly-metamorphic basements belonging to the Penninic nappe stack outcrop (e.g. Adula, Tambò, and Suretta nappes), divided by slices of metasedimentary cover (e.g. Splugen Zone and Misox Zone) and intruded by Permian and Oligocene metagranitoids and granitoids (e.g. Truzzo Granite, Bergell Pluton and Novate Granite). The nappe stack is juxtaposed by some structural and paleogeographic uncertain units, such as the Chiavenna Unit mafic-ultramafic complex (Schmid et al. 1996). To the South, the Insubric Line separates these tectonic units from the South Alpine metamorphic basement (Tonale Nappe) and its sedimentary series (Upper Orobic Nappe).
Even if the main activity of the CARG project is the collection of a complete set of geological and geomorphological data, scientific outreach and activities are a provided legacy of the project, promoting mutual interaction and sharing between the scientific community and the local population. To achieve the latter objective, the selection of intriguing and gripping topics could represent a good approach to stimulate the audience's attention and curiosity. In this context, local climbing sites can be an unusual but engaging subject (or even place) for scientific outreach, even though the collaboration with the local mountaineering clubs for organization and promotion of activities and meetings. The use of 3D Digital Outcrop Models that employ high resolution photogrammetric and point cloud data from Unmanned Aerial Vehicles, can help to make the topic more accessible and impressive. The possibility to communicate geology with an appealing approach for the population, together with the cultural value that the alpinist community attributed to rock climbing sites over time, as mentioned above, makes to consider climbing crags as geoheritage sites possible[3].
For this reason, we have selected six climbing sites, each one featuring peculiar lithology, geomorphological processes and structural settings. They represent a sample of Valchiavenna, Val Masino and Alto Lario geodiversity, and together they help outlining the geological, structural and geomorphological features of the study area (Fig. 1):

- Cimaganda bouldering site is located near the homonymous hamlet, on the left side of Val San Giacomo. The climbing area was formed as a result of a landslide that fell down from the mountain, damming the valley. The landslide body is made up of cyclopean blocks of different lithology, as Truzzo Granite and Tambo Nappe ortho- and para-derived rocks. The instability of the landslide niche and the neighbouring cliffs continues to occur, consequently, regular monitoring is essential to mitigate risks and ensure safe climbing.
- The Dalò via ferrata is located on the right flank of Val Bregaglia, above the small village of Pianazzola. It develops on a cliff that is composed of Permian meta-granitoids belonging to the Truzzo Granite intrusive body. The steep walls of the cliff represent the morphological expression of the lithological contrast between the metagranite and the surrounding lithologies (mainly paragneisses and amphibolites of the Tambo Nappe basement). The intrusive body features a high-variable rock texture and grain size. In the less deformed portions the rock is massive and characterized by centimetre-sized K-feldspar phenocrystals, which could be used as holds, while other portions are characterized by fine-grained centimetre- to decimetre-sized mylonitic and ultramylonitic bands that reduce the grip of the rock.
- The Uschione climbing area is located on the left flank of Val Bregaglia above the town of Chiavenna and in the core of the Chiavenna Unit, a mafic-ultramafic complex mainly composed of amphibolite (e.g. Fate Nere crag) and peridotite (e.g. Lottano Climb and Olimpo crags), intruded by granitic, aplitic and pegmatitic dykes of the Oligocene Novate Granite (e.g. Sasso Bianco and Tanno crags). Here, the climbing sites are characterized by a frictional style, as the consequence of the subglacial exharation that smoothed the rock outcrops.
- The Precipizio di Strem climbing crag is located in Val Bodengo, above the Corte Terza hamlet. Its peculiarity lies in the migmatitic texture of the outcropping rocks, which developed under high-grade metamorphism. Here, the Adula nappe orthogneiss underwent partial melting, segregating the melt into white layers called 'neosome' from darker ones of resistant rock called 'paleosome'. This results in a well-developed network on the cliff where the climbing routes develop, especially in the sector known as 'Ragnatela' (Italian word for "spider web"), where the rock's massiveness and the low presence of fractures promote a frictional climbing style.
- The Val di Mello climbing area, on the Raethian side of lower Valtellina, is characterized by outcrops of granodiorite belonging to the Oligocene Bergell intrusion. These rocks are also known with the local term 'Ghiandone', due to the presence of centimetre-sized phenocrysts of alkali feldspar. As for the Dalò crags, the preferential erosion preserves feldspar crystals and facilitates frictional climbing style. Additionally, holds or even climbing routes may follow rock exfoliation cracks. These features are typical of these kinds of rocks, generally related to weathering processes and to the stresses accumulated or induced within the rocks, even if the processes leading to their formations are complex and still debated. The intersection between different fault families and local cracks promotes the fall of cyclopean blocks, which represent a source of attraction for many boulderers. The most popular one is called 'Sasso Remenno', with an impressive volume of more than half a million m^3.
- Sasso Pelo climbing area develops between Gravedona ed Uniti and Peglio municipalities, in the Alto Lario area, a few kilometres beneath the Insubric Line. The climbing cliff is composed of dolomite that underwent weathering and carbonate dissolution, leading to the formation of karst structures, such as 'rillen karren' or 'alveoli'. These features give more grip for friction climbing.

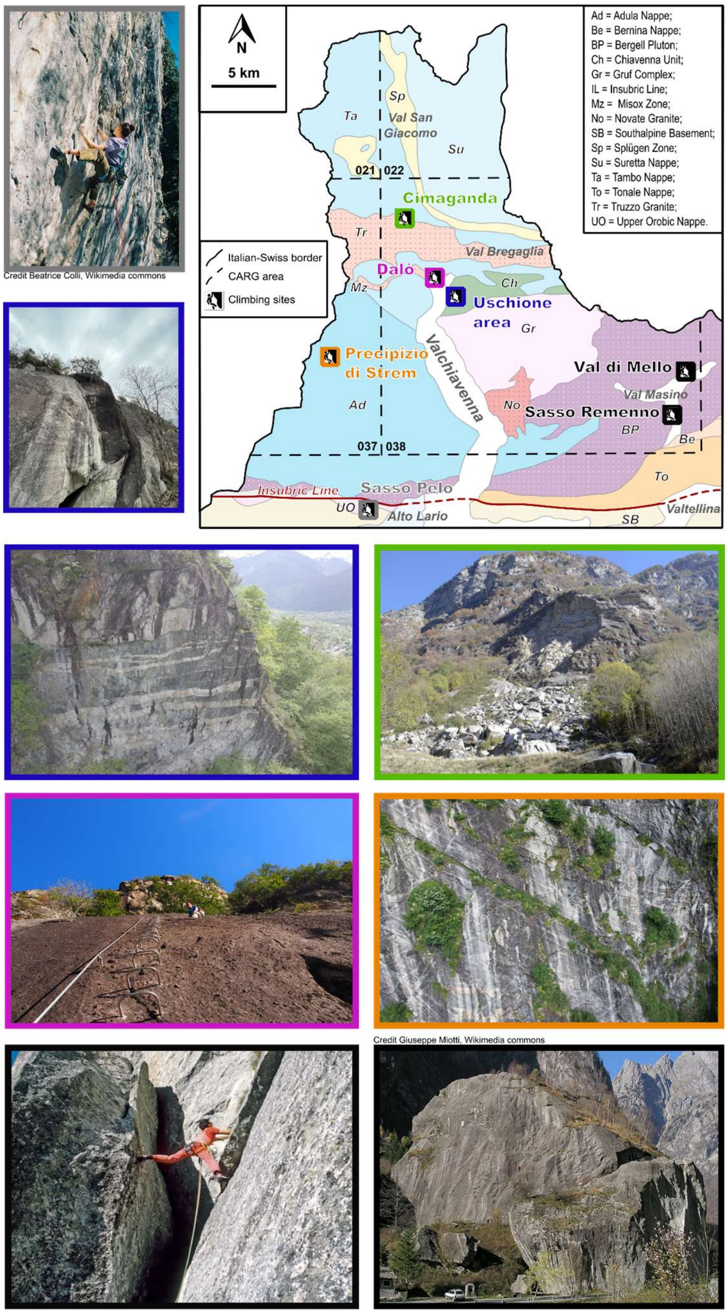

Figure 1. Tectonic sketch of the eastern Central Alps, in the area of Valchiavenna, Val Masino and Alto Lario, with the climbing sites. The colours of the photo borders correspond to the colours of the various climbing sites indicated on the central map. Redrawn and modified after Bigi et al. (1990).

Together, these climbing sites represent the geodiversity of the area and also could represent useful natural outreaches for the many attending climbers. Indeed, geological features are fundamental for the climbing style, since familiarity with the type of rock permits to know the critical issues of the climbing routes and to be more mentally and physically equipped, improving performance. Additionally, the knowledge of ongoing and future transformation processes would contribute to a greater awareness of the hazard and a reduction of personal risks associated with climbing. Recognizing climbing crags as sites for geoscience dissemination and geological heritage promotion can attract greater attention, fostering collaboration between scientists and institutions for their preservation. Highlighting their importance may also encourage public administrations to invest in sustainable management, ensuring accessibility and environmental protection. Scientific outreach can be accessed in various ways: by the installation of explanatory on-site panels; through the use of QR codes; by the participation of expert geologists in field activities organized by local recreational and sports associations; targeted activities with climbing groups. In order to enhance visitor experience by promoting geological knowledge and to recommend a safe climbing practice, as it was experienced, in the past, for the Ministerial strategic project AREE INTERNE *"School, mountains and sport: strategies and tools for Earth Sciences teaching and dissemination for the conservation and development of the mountain territory"*. The initiative involved the use of climbing walls for outside activities and students guided to observe and understand the rock faces while practicing their sporting skills [2].

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Analysis of the IUCN Key Biodiversity Areas (KBA) and their relationship with potential IUCN Key Geoheritage Areas (KGA): The prospective case study of Spain

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We examine the overlap between IUCN Key Biodiversity Areas (KBAs) and potential IUCN Key Geoheritage Areas (KGAs) in Spain, analysing the synergy between biodiversity and geoheritage conservation. The KBA programme, which has been established for some time by the International Union for Conservation of Nature (IUCN), focuses on areas that support species, ecosystems, and ecological integrity essential to global biodiversity. The KGA initiative, introduced at the 2018 ProGEO Symposium, and further developed after the 2020 IUCN World Conservation Congress (IUCN-WCC2020), aims to complement the IUCN nature conservation initiatives by identifying geosites of global significance and encouraging countries to ensure their conservation and proper management. This communication assesses the potential overlap between the two types of IUCN areas in Spain, with the goal of improving management strategies for integrated conservation of Nature.

KBAs are areas identified for their significant contribution to global biodiversity, supporting various species and ecosystems critical to their survival. They provide crucial ecological functions and serve as irreplaceable sites for conservation. KBAs play an essential role in global biodiversity conservation strategies, including the CBD Kunming-Montreal agreement, which targets expanding protected areas to cover 30% of the Earth's land and seas by 2030 [1]. In Spain, there are 471 KBAs, covering a total area of 23.67 million hectares, with 36.11% of this area being terrestrial and the remainder marine. While 19% of KBAs globally are fully protected, a significant portion of Spanish KBAs (39%) are unprotected, highlighting the importance of their conservation management (Figure 1).

The KGA initiative is intended to encourage countries to similarly protect geosites of international significance, which include geological features like rocks, minerals, fossils, landforms, and landscapes shaped by various geological processes. Resolution 074 of the IUCN-WCC2020 recognized the need for an initiative focused on KGAs, encouraging further study to complement the KBA programme and protect geosites of international significance globally [2]. This initiative is set to expand the focus of conservation to encompass geological as well as biodiversity heritage values, with an emphasis on the integrated conservation of both biotic and abiotic elements of Nature.

We have selected the Spanish case study for its wealth of data and previous works. Spain's involvement in the Global Geosites Project, initiated in 1999 by the Spanish Geological Survey (IGME-CSIC) [3] and maintained by the Spanish government in the Spanish inventory of geosites (IELIG), provides an extensive inventory of geosites with global relevance. The methodology employed for this project followed a two-step process: selecting significant geological frameworks in each country and identifying representative geosites within these frameworks (García-Cortés, 2009). Considering the effort made in Spain through the Global Geosites Project, the recent International Union of Geological Sciences (IUGS) Geological Heritage Site identifications made by its Geoheritage Commission, the listed Global Boundary Stratotype Section and Points (GSSP) of the IUGS´s International Commission on Stratigraphy and the World Heritage (WH) sites identified under Criterium VIII by UNESCO, it could state that the study of potential KGAs in Spain is largely complete. Once the KGA initiative is formally adopted by the IUCN in 2025, The Spanish list of Global Geosites (including those recently identified by the IUGS Geoheritage Commission) could be fast-tracked into the KGA list.

As of January 2025, Spain comprehends 252 Global Geosites, 7 IUGS Geological Heritage Sites, 8 GSSPs, and 4 WH sites identified under Criterium VIII by UNESCO, which span around 405,000 hectares. This area is only 1.7% of the total area covered by KBAs in the country (Figure 1). Interestingly, 159 of the potential KGAs (63%) overlap with KBAs, covering 78% of the total KGA area. Most of these overlaps (147 sites) are almost fully contained within KBAs (80-100%), indicating a strong correlation between these two conservation priorities. The overlap between KBAs and KGAs is primarily concentrated in coastal and littoral deposits, fluvial and aeolian deposits, and areas influenced by climatic factors.

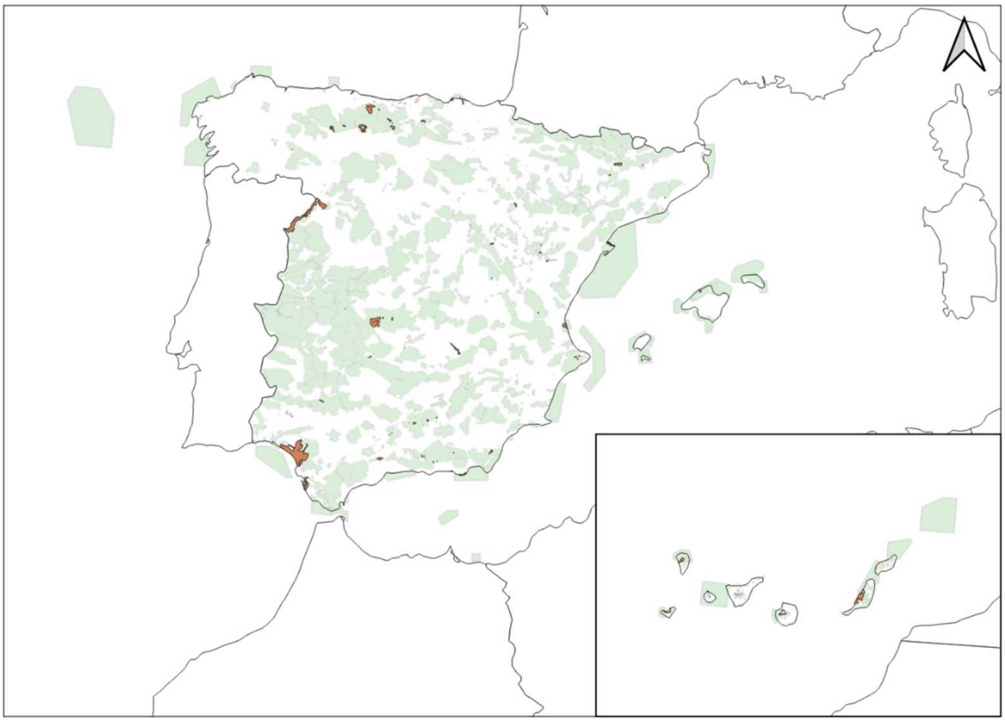
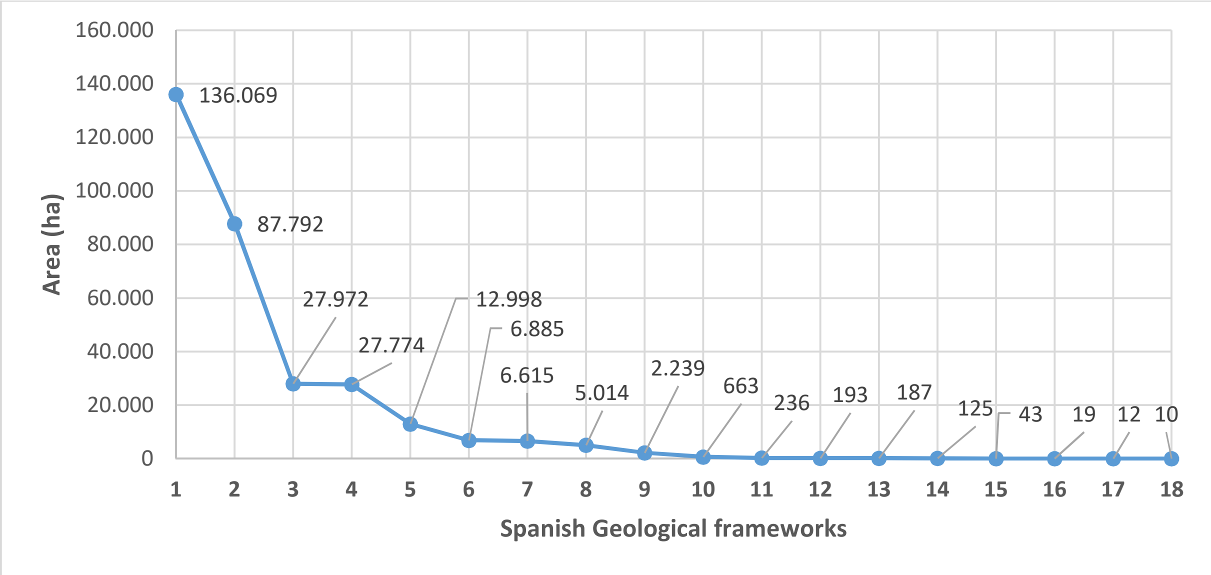


Figure 1. Potential KGAs (in orange, source: IGME-CSIC) compared with KBAs (in green, source: KBA initiative) in Spain.

The geological units and frameworks that exhibit the greatest overlap with KBAs include coastal areas, river systems, volcanic regions, and karst systems (Figure 2). The management of these overlapping areas can benefit both geoheritage and biodiversity conservation. The analysis reveals that the potential KGAs occupy a significantly smaller area compared to the KBAs (Figure 1), which suggests that the impact of KGA designation on the overall KBAs in Spain will be minimal. However, the overlap between the two areas indicates that a large portion of potential KGAs lies within existing KBAs. This overlap could facilitate integrated management strategies that address both biodiversity and geoheritage, ensuring the conservation of both. Most of the overlapping KGAs are related to coastal and littoral deposits and landforms, which are under threat from rising sea levels, increased storms, and urbanization. These threats are like those faced by KBAs in coastal regions. By addressing these threats through geoconservation measures, the conservation status of both the geosites and the associated biodiversity can be enhanced. Geological units related to fluvial and aeolian deposits, as well as climatic action, also overlap with KBAs and have the potential to influence the conservation of habitats and species. Protection measures for these areas could contribute to the favourable conservation status of the associated KBAs. Volcanic and karst systems, while covering a smaller area, around 27,000 ha), also present significant overlap with KBAs (Figure 2).



Geological framework	Number	Area (ha)	Number of overlapped potential KGAs
Coasts of the Iberian Peninsula.	1	136.069	26
Fluvial network, ravines and Appalachian landscapes of the Iberian Massif.	2	87.792	5
Volcanic buildings and morphologies of the Canary Islands.	3	27.972	23
Karstic systems in carbonates and evaporites of the Iberian Peninsula and Balearic Islands.	4	27.774	26
The Iberian Variscan orogen.	5	12.998	13
Stratigraphic series of the Lower and Middle Palaeozoic of the Iberian Massif.	6	6.885	8
The rifting of Pangea and the Mesozoic successions of the Betic and Iberian mountain ranges.	7	6.615	22
South-Pyrenean synorogenic basins.	8	5.014	4
The Carboniferous of the Cantabrian Zone.	9	2.239	3
Miocene extension in the Alboran Domain.	10	663	7
Messinian evaporite episodes (Mediterranean salinity crisis).	11	236	4
Mercury mineralisations from the Almadén region.	12	193	4
Ophiolithic complexes of the Iberian Peninsula.	13	187	1
Fossils and ichnofossils from the continental Mesozoic of the Iberian Peninsula.	14	125	7
Tertiary continental basins and associated vertebrate deposits in the Spanish Levant.	15	43	1
Neogene and Quaternary volcanism of the Iberian Peninsula.	16	19	2
Spanish Plio-Pleistocene vertebrate sites.	17	12	1
Olistostromic units of the Betic foreland.	18	10	2

Figure 2. Overlapping area of potential KGAs with KBAs in relation to the Spanish geological frameworks. 1. Coasts of the Iberian Peninsula; 2. Fluvial network, ravines, and Appalachian landscapes of the Iberian Massif; 3. Volcanic buildings and morphologies of the Canary Islands; 4. Karstic systems in carbonates and evaporites of the Iberian Peninsula and Balearic Islands; 5. The Iberian Variscan orogen; 6. Stratigraphic series of the Lower and Middle Palaeozoic of the Iberian Massif; 7. The rifting of Pangea and the Mesozoic successions of the Betic and Iberian mountain ranges; 8. South-Pyrenean synorogenic basins; 9. The Carboniferous of the Cantabrian Zone; 10. Miocene extension in the Alboran Domain; 11. Messinian evaporite episodes (Mediterranean salinity crisis); 12. Mercury mineralisations from the Almadén region; 13. Ophiolithic complexes of the Iberian Peninsula; 14. Fossils and ichnofossils from the continental Mesozoic of the Iberian Peninsula; 15. Tertiary continental basins and associated vertebrate deposits in the Spanish Levant; 16. Neogene and Quaternary volcanism of the Iberian Peninsula; 17. Spanish Plio-Pleistocene vertebrate sites; 18. Olistostromic units of the Betic foreland.

These geological features influence soil properties and ecosystems, affecting vegetation and wildlife. The management of these areas requires attention to both geological and ecological considerations, ensuring that both geoheritage and biodiversity are adequately protected. The integration of geoheritage and biodiversity management requires the training of Protected Area´s (PA´s) managers in both geoconservation and biodiversity conservation, ensuring that both aspects are properly managed in parallel. By adopting a collaborative approach, the management of overlapping KBAs and KGAs can maximize conservation outcomes for both geoheritage and biodiversity.

The analysis of potential KGAs in Spain reveals several key findings:

❖ Area Comparison: The total area occupied by KGAs is significantly smaller than the area covered by KBAs, with KGAs occupying only 1.7% of the total KBA area. The declaration of KGAs will have a minimal impact on the spatial extent of KBAs in Spain.
❖ Management Integration: The high degree of overlap between KBAs and KGAs suggests that the management strategies for KBAs could be adapted to include the protection of geoheritage. Geosites typically follow nature-based solutions that have minimal local impact, making their management complementary to biodiversity conservation goals.
❖ Coastal and Littoral Focus: The majority of overlapping KGAs are in coastal and littoral areas, which are vulnerable to climate change impacts. Effective management of these areas will require addressing both threats to geoheritage and biodiversity.
❖ Fluvial and Aeolian Processes: KGAs related to fluvial and aeolian deposits, as well as climatic landforms, play a significant role in shaping the habitats of various species. Protecting these geological processes will contribute to the conservation of biodiversity within the overlapping KBAs.
❖ Volcanic and Karst Systems: The management of ancient volcanic and actual karst systems requires attention to both geological features and the biodiversity they support. Proper management of geosites will help ensure the conservation of species and habitats associated with these areas.
❖ Training and Collaboration: Effective management of overlapping KBAs and KGAs will require PA managers to be trained in both geoconservation and biodiversity conservation. Collaborative management approaches will maximize conservation outcomes for both geoheritage and biodiversity.
❖ Overall Conservation Benefits: The integration of geoheritage and biodiversity conservation through the designation of KGAs and their overlap with KBAs provides a holistic approach to Nature conservation. By recognizing the interdependence of biotic and abiotic elements of Nature, this approach ensures more effective and comprehensive conservation efforts.

In conclusion, the establishment of KGAs in areas that overlap with KBAs offers a unique opportunity to enhance conservation efforts by integrating the protection of both geoheritage and biodiversity. This integrated approach will ensure that the whole Nature is preserved for future generations.

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Law protection and review of the Umbria Region's geosites: obstacle or opportunity?

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The “Regione Umbria” has been protecting geosites since 2000 by Regional Law no. 27 [1]. That protection was confirmed by the Regional Law no. 1/2015 [2] which, in its article 86, establishes the geosite list for this region. As geosites have public interest, in these areas it is not allowed to make: dumps, tree planting, agricultural activities that damage the geosite, water extraction, any alteration of the surface or the groundwater system, damaging infrastructures except hiking path networks or, any activity that could cause degradation or destruction of the geosites. The regional geological department is in charge of the updating of the geosites list, in collaboration with a board named "Geological heritage" established by the Executive Board of the State-Regions and the Geological Committee of the Autonomous Provinces which is part of the Institute for Environmental Protection and Research (ISPRA). The updating of the inventory started in 2021 and ended in 2024. the updating, in relation to the 43 previous geosites, confirmed 24 geosites, added 8 geosites, 3 new geosites were established and 8 were deleted [3]. Since detailed geological information is available for the whole regional territory, ten different kinds of landscape geological form or characteristic were identified [4], then they were reduced to five.
Every year, the Regional Geological department, by issuing hundreds of geological reports, ensures that the geosites do not get damaged or altered in any way. In that respect, during the last 25 years no problems have occurred.
For some geosites, private business including geotourist activities was established, also supported by the local municipality which rules tourists access and provides information by setting up thematic museums. The Regional Geological department has set up a specific geo-tourist route, available online at https://www.regione.umbria.it/paesaggio-urbanistica/percorso-geo-turistico-sant-anatolia-di-narco-norcia , that has already been visited by thousands of users [5].
After thirty years, it is possible to say that the daily activity of the “Regione Umbria” Geological department helped by protecting the geosites from any damage. We consider this protection has not been an obstacle to development, but rather an opportunity to establish projects of territory enhancement for an aware tourism.

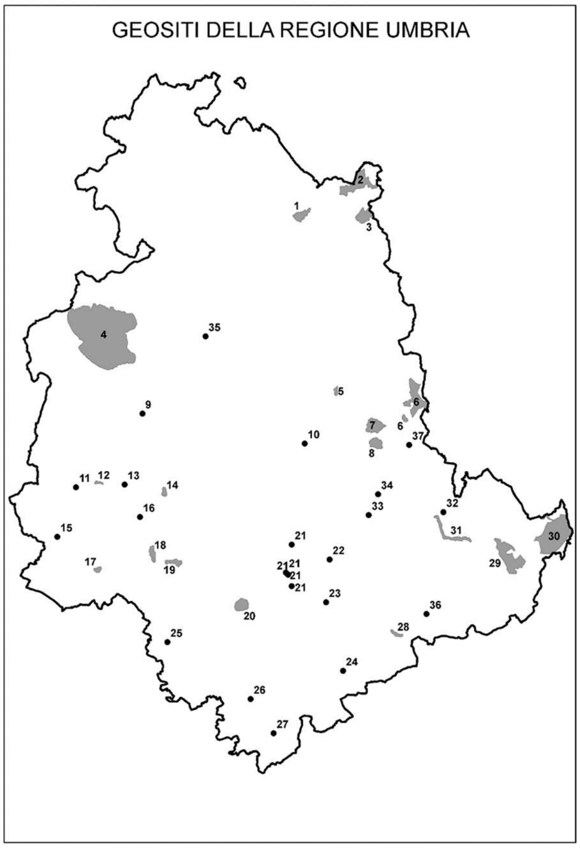

Figure 1. Geosites of the “Regione Umbria”.

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20 years of the Geoconservation Award (2004-2024): ProGEO Portugal efforts in recognising local geoconservation initiatives

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Geoconservation is not limited to strategies and actions undertaken by national governments, central administrations, or entities dedicated to nature conservation. Local administration initiatives can play a crucial role in geoconservation by granting local legal status to geosites or implementing projects aimed at their protection, educational enrichment, and tourism development. Globally, the significance of this localized approach has become increasingly evident, particularly in contexts where national governments fail to take responsibility for the conservation of geological heritage.

Within this framework, in 2004, the Portuguese ProGEO group established the Geoconservation Award (GA) to recognize best practices in geoconservation promoted by municipalities. The objectives of this award include fostering discussions on the importance of geological heritage protection, encouraging municipalities to adopt geosite conservation strategies, raising societal awareness about integrating geological heritage into nature conservation and land-use policies, and promoting geology in the media agenda [1].

Each year, the GA is open to all Portuguese municipalities, which can apply by submitting a simple form with general information and an application dossier. The application deadlines have varied over the years, primarily to align with commemorative dates related to geoconservation. Until 2021, applications were due by the end of February, and the award was presented in an open ceremony, usually held at the City Hall of the winning municipality, on April 22, in celebration of International Earth Day and the National Geological Heritage Day, proclaimed by ProGEO Portugal. Following UNESCO's establishment of the International Geodiversity Day in 2021, the ceremony is now held on October 6. Consequently, the application deadline has been adjusted to the end of June, with evaluations conducted until September.

Currently, the jury consists of two ProGEO delegates (one serving as the jury president) and representatives from the following institutions: the Portuguese Geological Survey (Engineering and Geology National Laboratory - LNEG), the Portuguese Geologists Association (APG), the Institute for Nature Conservation and Forestry (ICNF), and the General Directorate of Energy and Geology (DGEG). The evaluation criteria include: i) Inventorying geosites and ensuring scientific validation; ii) Implementation of geosite conservation measures; iii) Strategies for geosite promotion and interpretation.

Over 20 years of the award, more than 100 applications have been received, and 46 municipalities have been awarded (Fig. 1), representing 14.5% of the Portuguese territory. In certain editions, groups of municipalities have applied jointly, particularly when collaborating on geopark initiatives. Moreover, some municipalities have been awarded twice, such as Arouca, Castelo Branco, Idanha-a-Nova, Torres Novas, Valongo and Viana do Castelo.

Beyond recognizing municipal geoconservation efforts, the GA serves as a key communication tool for promoting geological heritage and its valorisation. The award process includes a communication strategy that publicizes both the launch and annual award announcement. Moreover, it fosters collaboration among participating institutions, leading to additional projects and partnerships.

Over the past two decades, this Portuguese initiative has proven to be a successful model, as evidenced by the growing interest of municipalities in receiving ProGEO recognition. In many cases, the prospect of obtaining the award has motivated the implementation of local geoconservation initiatives. We believe that this model could be adopted by national ProGEO groups in other countries.

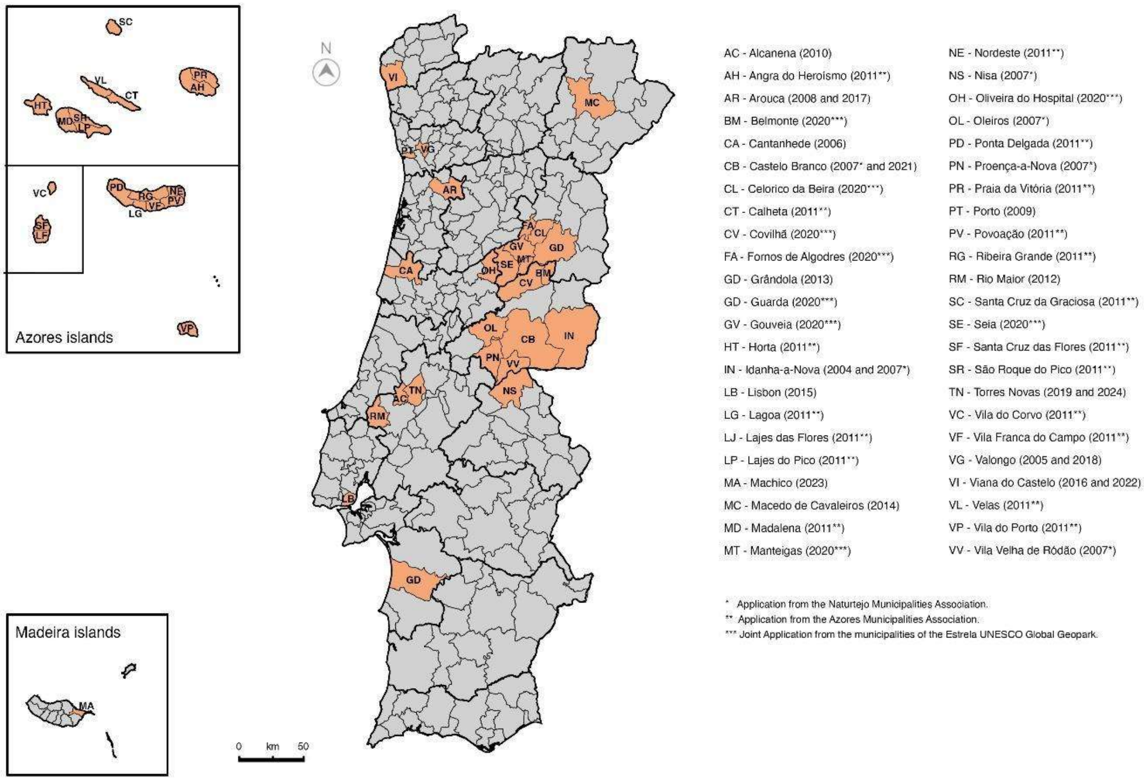

Figure 1. Portuguese municipalities that have been honoured with the Geoconservation Award issued by ProGEO Portugal since 2004.

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SESSION 2: GEOHERITAGE AND TERRITORIAL PLANNING

Convener: Manu Monge-Ganuzas

Geodiversity, functions, ecosystem services: What are they and how to integrate them within land-planning? (Invited Keynote)
Scammacca O.

Identifying the UNESCO Global Geopark potential in mainland Portugal
Costa M., Pereira P.

Recognition of mine structures based on georeferenced maps of the "Cerasara" mine of Caulonia and Roccella Ionica (Calabria - Southern Italy)
Dattola L., Cirrincione R., Critelli S.

Volcanic geoheritage in monogenetic basaltic volcanism: 1909 Chinyero the last eruption of Tenerife (Canary Islands, Spain)
Dóniz-Páez J., Becerra-Ramírez R., Cornejo-Nieto C., Beltrán-Yanes E.

Inventory and evaluation of the geoheritage at the municipality of Ansião, Portugal
Forte J.

Tools for the management and planning of the landscape and agricultural spaces of the Orígens Geopark
Pellicer X.M., Puras G., Mallol P., Francés M.

INVITED KEYNOTE

Geodiversity, functions, ecosystem services : what are they and how to integrate them within land-planning ?

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Geodiversity assessment gained a prominent interest in the geoscientific community and beyond. However, assessing the richness, abundance or diversity of entities of different nature in a given area is not always sufficient for land planning or geoconservation. It is then pivotal to account for the contributions that geodiversity provides to human societies, i.e. functional geodiversity or geofonctionnality [1].
The assessment of functional geodiversity can be assessed through multiple methods. One of them is to decline the "ecosystem services" (ES) paradigm to geodiversity, as suggested by many authors [2,3,4]. Indeed, this concept has been traditionally applied to biodiversity-related services while soil-related services have been increasingly studied only in the last decades and geodiversity was regarded as provider of "abiotic" and "supplementary services" in the major international classification systems [5]. Geodiversity plays a key-role in delivering a wide range of provisioning (e.g. raw materials, water, fibers and food), regulating (e.g. habitat support, nutrient cycling, natural hazard control) and cultural services (e.g. geotourism, recreational activities) [2,6]. ES, as the benefits that nature supplies to human societies, are the result of complex interactions between geodiversity and biodiversity. This paradigm offers an operational tool, prone to assessing and mapping exercises, to integrate natural diversity and their contributions to human societies through a utilitarian approach. Although criticizable and criticized, the ES concept allows a systemic analysis of the variability of both biotic and abiotic properties the related functions and of how such functions satisfy or may satisfy human needs and are apprehended whenever they are beneficial to human societies, translating a wide range of potential land planning strategies (Fig.1). While the application of this concept to geodiversity is still in progress and definitions are not unanimous (Frisk et al. 2022), many studies attempted to assess and map geodiversity-related ES (GES) in multiple contexts through qualitative and quantitative methods [1,8,9,10]. This presentation proposes a general overview about the declination of the ES concept to geodiversity, with a particular focus on indicator-based assessments applied to the example of French Guiana, a French and European Overseas territory located in South America.

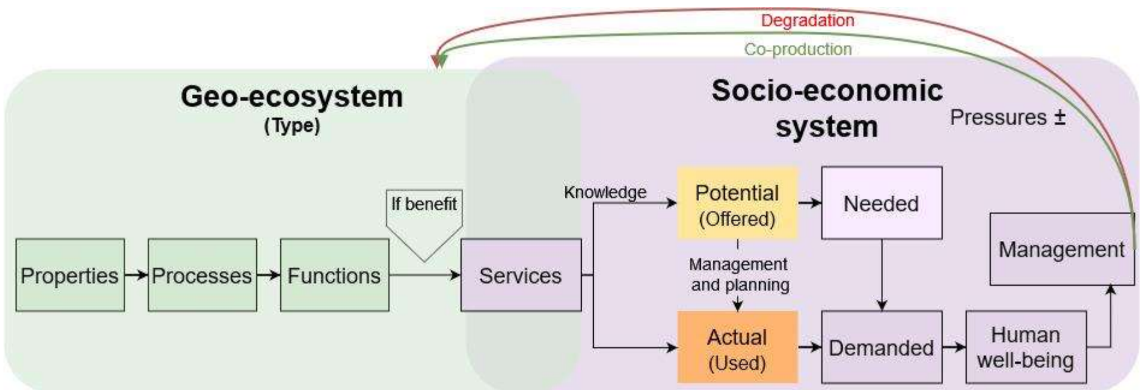

Figure 1. ES cascade model [1], adaptable to both biodiversity and geodiversity-related ecosystem services. The framework distinguishes between potential and actual services based on the approach proposed by [7].

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Identifying the UNESCO Global Geopark potential in mainland Portugal

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UNESCO Global Geoparks (UGGps) are a tool for the sustainable development of territories based on the values of their geological elements [1]. The establishment of the International Geoscience and Geoparks Programme of UNESCO Programme has contributed to the global popularization of UGGps and has spurred increasing interest in obtaining this prestigious designation. In Portugal, six territories have already been designated as UGGp, collectively covering approximately 12.8 % of the national territory. Several additional projects are underway to achieve similar recognition. However, no standardized criteria or regulations currently exist for identifying and evaluating areas with the highest potential to become UGGp, nor has a discussion been initiated regarding the optimal number of UGGps or the total area that can be designated within each country.

Such discussions should incorporate criteria considered essential by UNESCO, including the presence of internationally significant geoheritage, other natural and cultural assets, and the potential for these resources to drive socio-economic development in less advantaged regions [1,2]. To address this gap, a numerical methodology was developed and applied to the 278 municipalities of mainland Portugal to assess their potential for designation as a UGGp [3].

All municipalities were evaluated, irrespective of their current inclusion in an existing UGGp. The assessment utilized a scoring system with a maximum of 100 points, based on five key criteria: (i) geoheritage significance, (ii) geoheritage potential use, (iii) existence of other types of heritage, (iv) geodiversity, and (v) socio-economic conditions. Geoheritage significance (maximum 50 points) and potential use (maximum 15 points) were evaluated using data from the national inventory of geosites with national and international relevance. The significance criterion accounted for local, national, and international scientific relevance of the geosites, as well as alignment with geological frameworks representing Portugal's geoheritage. The potential use criterion considered indicators such as land ownership, protection status, vulnerability to human and natural processes, and the presence of infrastructure and valorization tools. The presence of other heritage types (maximum 10 points) was assessed by identifying additional legally protected natural and cultural sites. While geodiversity distribution does not directly correlate with geoheritage occurrence, it was included in the assessment due to its role in enhancing territorial attractiveness [4]. Accordingly, data on the spatial distribution of geomorphological and lithological diversity in mainland Portugal [5] were incorporated, with greater weight given to geomorphological features. Socio-economic conditions (maximum 15 points) were evaluated based on indicators such as demographics, employment rates, income levels, and access to education and healthcare services.

The resulting UGGp potential index for the 278 municipalities of mainland Portugal (Fig. 1a) comprises scores ranging from 14 to 87 points. The findings indicate that while some municipalities with high scores are already part of existing UGGp, others with comparable or even higher scores are not yet designated. Conversely, certain municipalities currently included in UGGp exhibited relatively low scores, suggesting that their designation may be contingent on their association with neighboring municipalities of higher potential.

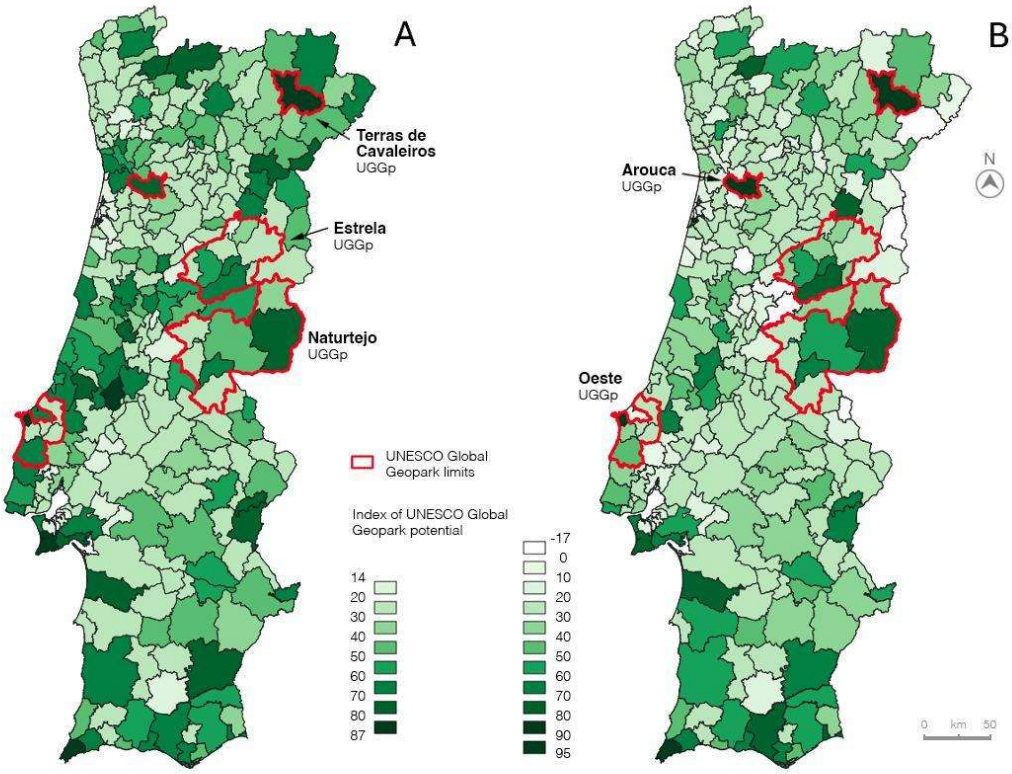

Figure 1. Index of UNESCO Global Geopark (UGGp) potential in mainland Portugal municipalities: a) index obtained according to the geoheritage significance, geoheritage potential use, existence of other types of heritage, geodiversity, and socio-economic conditions; b) combined index that also takes into account the current UGGp and local initiatives regarding the protection and promotion of geoheritage.

To enhance practical applicability, the analysis was refined to focus on municipalities not currently included in existing UGGp. Adjustments were made to the initial scores by deducting points for municipalities where geosites were already represented in existing geological frameworks (up to 10 points), where a UGGp is already present in the region (up to 10 points), and where proximity to an existing UGGp was deemed a limiting factor (up to 10 points). Conversely, points were added for municipalities recognized for their geoheritage conservation efforts (up to 5 points), those with established protected areas specifically designated for geosites (up to 5 points), and those utilizing mining heritage for educational, scientific, and tourism purposes. The latter assessment incorporated data from the ProGEO Portugal Geoconservation Award, local protected areas, and the "Route of Portugal's Mines and Mining and Geological Points of Interest" initiative.

A final combined index of UGGp potential was obtained for all municipalities (Fig. 1b), with scores ranging from -17 to 95 points. The revised analysis revealed that some municipalities already included in UGGp, such as Arouca and Macedo de Cavaleiros, had their scores increased. However, the most significant findings are the substantial changes observed in many of the non-UGGp municipalities, with some even obtaining negative scores while others obtained an increase. By taking into account the limitations imposed by the existence of territories already classified under the UGGp Programme and demonstrating greater discrimination between municipalities, this combined index appears to be more effective in identifying UGGp potential.

The two-step methodological approach aimed to assess whether the current UGGp-designated municipalities meet UNESCO's criteria while identifying other municipalities with significant potential for future designation. The methodology is designed to be straightforward and accessible, though its results are heavily dependent on the availability of supporting data. The absence of comprehensive geodiversity data for Madeira and the Azores prevented the inclusion of these regions in the analysis. Furthermore, a significant portion of the evaluation relied on the national geosite inventory, which is currently undergoing revision and expansion. The establishment of a robust and objective inventory methodology is crucial for such assessments. Specifically, incorporating geosites of local significance and better differentiating between geosites of national and international importance would enhance the reliability of the results, given that international geological

heritage is a key factor for UGGp designation.
It is hoped that this methodology can inspire similar approaches in other regions, fostering further discussions and refinements. In this context, the development of standardized guidelines for assessing UNESCO Global Geoparks potential would be beneficial, ensuring consistent evaluation procedures across different countries and improving the fairness and transparency of UGGp designation processes.

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Recognition of mine structures based on georeferenced maps of the "Cerasara" mine of Caulonia and Roccella Ionica (Calabria - Southern Italy)

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The historical memory of mining activities in old Calabrian mining areas has often been lost, leaving only old documents as the sole records that can be useful for reconstructing the structures and their functions.
Abandoned mining areas frequently undergo spontaneous rewilding, with vegetation reclaiming the spaces once occupied by mining activities. This process limits the overall view of the site and makes it difficult to locate the remnant structures.

This work partially retraces the historical and mining events of the "Cerasara" mine, from which arsenopyrite was extracted during the period between the two world wars and until shortly after the end of the second conflict. The mining operations were granted to the Rumianca company, which took the name of the municipality in which it was based: the municipality of Rumianca (now Pieve Vergonte, in the Verbano-Cusio-Ossola province). At that time, Rumianca held mining concessions in various Italian regions, including Calabria.

The mine is located within the municipal territories of Caulonia and Roccella Ionica, in the southern Ionian Calabria region. It is set in an environment of Mediterranean scrub and woodland, which have partially rewilded the area, making exploration and the identification of mining structures difficult.

The study aims to develop and field-test a method capable, under certain conditions, of addressing the study of abandoned mining sites using old georeferenced mining maps, assess its characteristics, and locate and identify structures, even if they are hidden in dense vegetation or nearly buried under debris.
These activities respond to the needs expressed by local authorities (municipalities, park agencies, regional bodies) to re-evaluate sites that once had a significant economic and industrial cultural impact on the local population. Today, almost completely forgotten, these sites could foster a sustainable economy based on geo-tourism.

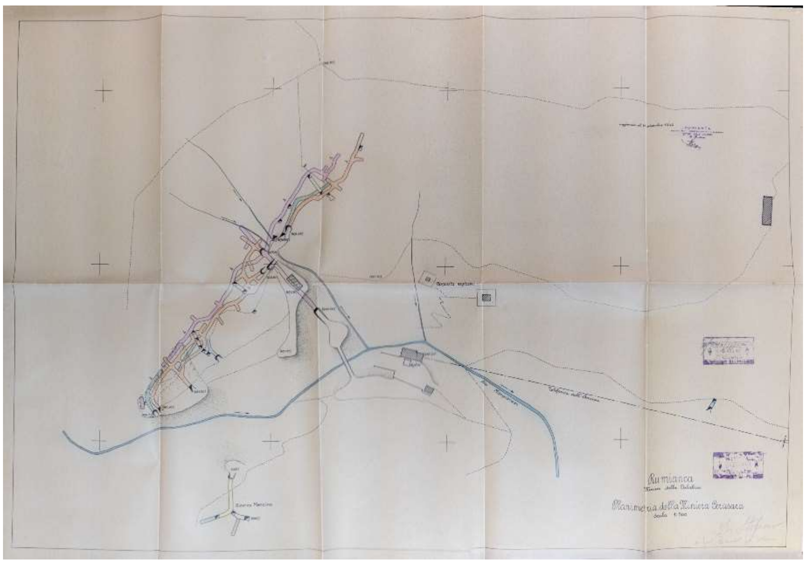

Figure 1. Cerasara mine map – 1947.


Figure 2. Arsenopiryte veins.

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Volcanic geoheritage in monogenetic basaltic volcanism: 1909 Chinyero the last eruption of Tenerife (Canary Islands, Spain)

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Studies on geoheritage have been expanding its scope to cover different geological and geomorphological contexts. Following this trend, research on volcanic areas has also increased in recent years, and has contributed to territorial planning [1]. Volcanic landscapes represent very attractive places for its inhabitants and offer many resources to the communities that live within them (soils, materials, energy, tourism or cultural heritage). However, the main attraction that volcanoes offer is related to volcanic heritage and geotourism. Many studies refer to volcanic regions, islands, stratovolcanoes or monogenetic volcanic fields, but fewer studies have focused on specific spaces at a detailed scale. A possible reason for such a trend could be because a detailed knowledge of the volcano is required in such studies to encapsulate its geodiversity at a detailed scale. This work aims to fill this gap by studying the volcanic geoheritage of a small monogenetic basaltic eruption at Chinyero that took place in 1909 in Tenerife (Canary Islands, Spain) (Fig. 1).

Figure 1. Chinyero eruption: the eruptive column (gases, ash and lapilli) from the main cinder cone with Strombolian explosions and the aa lava flows emitted in 1909. Source: Diario de Avisos, 2002.

To analyse the geoheritage of Chinyero volcano (CHV), we created an inventory of volcanic and non-volcanic geoforms generated during and after the eruption based on a literature review, photographs of the eruption, topographic, geological and geomorphological mapping, DTMs, photo-interpretation and fieldwork.

CHV (28º 17´41.26´´N 16º 45´25.54´´W) is located around 1500 metres above sea level in the Bilma volcanic rift (BVR) and is the last volcano to erupt in Tenerife. The CHV is the result of a monogenetic basaltic eruption that occurred in Tenerife between 19 and 28 November 1909. CHV is a NW-SE fissural eruption of 0.7 km in length in which volcanic activity was concentrated at the ends of the fracture, generating two cinder or scoria cones of different size and morphology. During the active period the eruption had a Strombolian dynamic with violent Strombolian pulses with eruptive columns (maximum 250 metres high) [2] with emission of ash, lapilli, scoria and bombs and different lava flows (Fig. 2). CHV is currently part of the Chinyero Special Nature Reserve which covers an area of 23.794 km^2 and includes other scoria cones such as those from the Arenas Negras eruption of 1706 that destroyed the town and seaport of Garachico. The area where the 1909 eruption took place was a cereal-growing area and traces of its agricultural past can still be recognised today with the presence of stone walls associated with abandoned terraces [3]. In the reserve, Canarian pine (*Pinus canariensis*) plantations have been established and currently, the main activities here are related to geotourism through hiking.

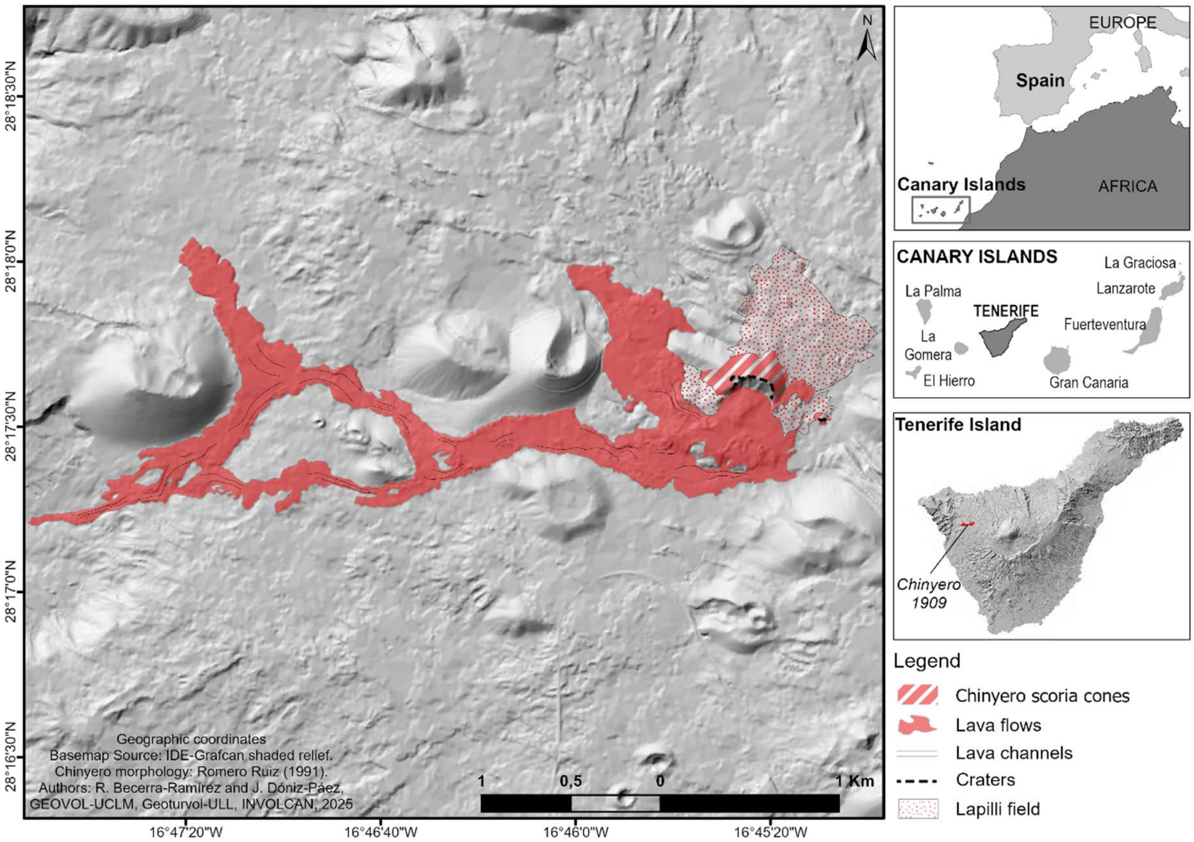

Figure 2. Chinyero volcano location and geomorphological scheme. Source: IDE-Canarias, GEOVOL-UCLM, Geoturvol, Involcan elaboration.

BVR is one of the five major morphostructures of the Tenerife relief (two ancient volcanic massif of shield volcanoes, two volcanic rifts and the Cañadas-Pico Viejo-Teide volcanic complex) and is composed of 46 cinder or scoria cones (15.48% of total in Tenerife) with different morphology grouped around a NW-SE axis and lava ridges. BVR is a young geological structure and its predominant geoforms are eruptive, but the morphologies associated with posteruptive processes are of lesser importance.

According to Dóniz-Páez et al., 2020 [4] the diversity of geoforms in the Canary Islands can be divided into direct volcanic forms/processes or non-volcanic landforms/processes. In the first case, they can be grouped into the volcanic edifices (monogenetic –cinder or scoria cones, hornitos, domes, maars, tuff rings and tuff cones-, polymagmatic and polygenetic volcanoes –lava shield volcanoes, volcanic rifts, lava dome and stratovolcanoes-), lava flows (terrestrial and submarines) and others (dykes, necks, faults, etc.). The non-volcanic geoforms are recent geomorphological features (ravines, cliffs, beaches, periglacial, slope deposits, others), relict and giant landslides.

The volcanic cones formed during the eruption correspond to two basaltic scoria cones built by basaltic ash, lapilli and scoria products. The main cinder cone, about 80 m high (Fig. 3a), is located NE of the fracture, has an open-arch morphology and emitted two lava flows with a covered area of 2.34 km^2, a maximum length of 4.5 km, with an average thickness of 5-6 m and an approximate volume of 16,295 m^3 [4]. The smaller scoria cone, only 10 m high, is located SW of the fissure and has several annular and open craters and emitted a short aa lava flow of about 5 metres (Fig. 3b).

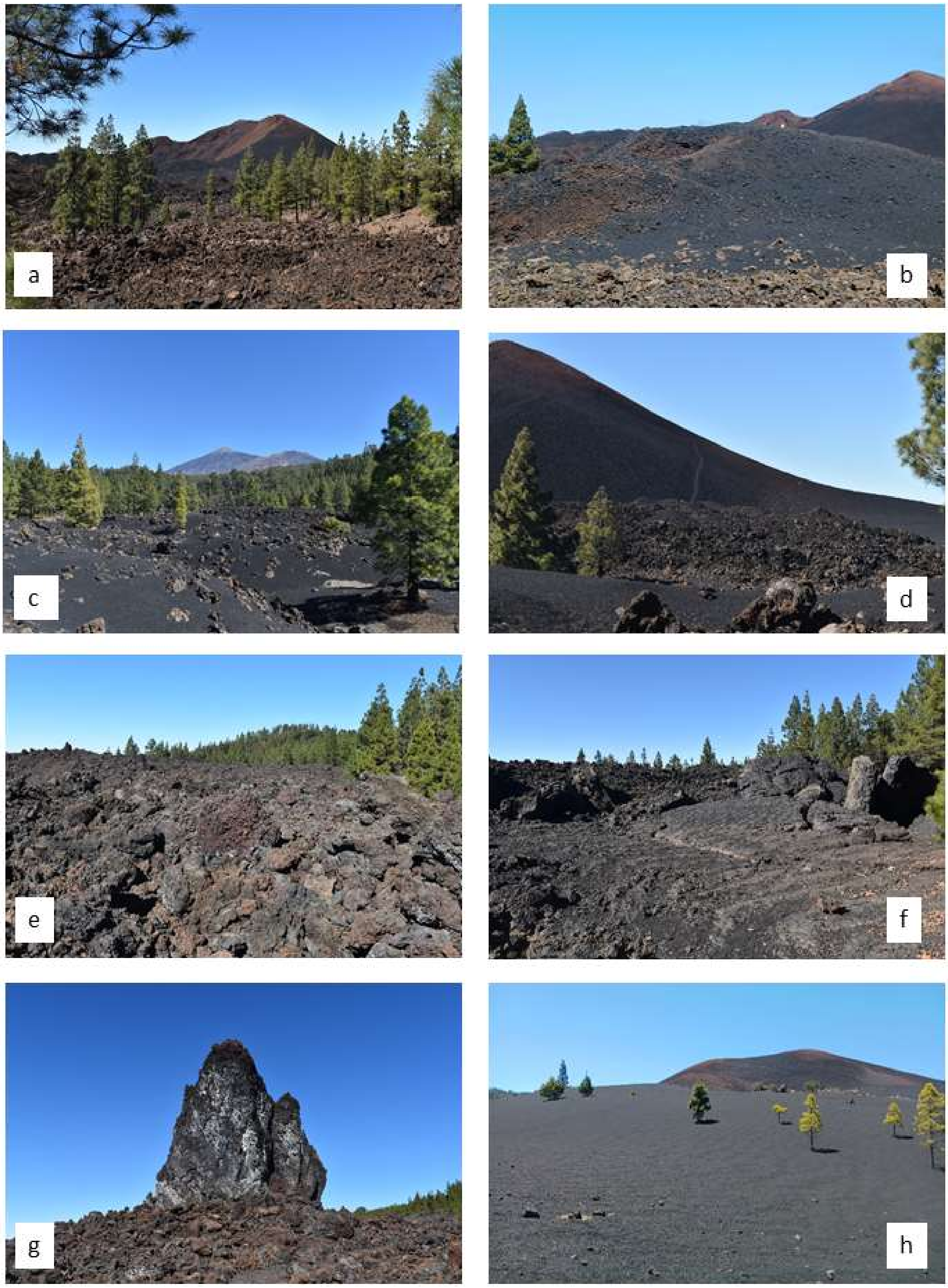

Figure 3. Geoforms in Chinyero monogenetic volcano: a-main scoria or cinder cone. b-small scoria cone. c-lapilli field. d-hydromagmatic geoforms. e-aa lava flows. f-pahoehoe lava flows. g-erratic blocks. h-ripples. Source: the authors.

The lapilli field is located north of the main volcanic cone (Fig.3c). The wind was the main factor that tilted the eruptive column to the north. Historical photographs of the eruption and engravings provide clear evidence of this phenomenon (Fig. 1). Pyroclastic materials were also emitted after the lava flows, which is why in the vicinity of the volcanic cones, the lava is partially covered by lapilli. In several areas of the lava emitted from the main cinder cone, small elevations have been recognized above the aa lava, which have been interpreted as hydromagmatic geoforms (Fig. 3d).

The lava emitted during the eruption were aa (Fig. 3e), aa transition to pahoehoe and pahoehoe (Fig. 3f). The aa lava flows are characterised by a chaotic surface, blocks of different sizes and several lava channels with levees, some accretion balls and several erratic blocks up to 5 m high that were part of the main volcanic cone (Fig. 3g). The pahoehoe lavas are characterised by continuous surfaces with different slab or ropy

morphologies.
The main non-volcanic geoforms are associated with aeolian processes and the formation of ripples in the lapilli field and the northern ridge of the main cone (Fig. 3h); with slope dynamics processes inside the arc craters and erratic blocks with the formation of taluses; with the formation of small gullies associated with pyroclasts and incipient periglacial forms.
In general, the geodiversity of the CHV, in relation to the inventories available for the Canary Islands or other monogenetic volcanoes, is average. However, the interest of this monogenetic basaltic volcano is that its natural and cultural heritage is preserved. Furthermore, since its eruption, this location has evoked scientific, educational and touristic interest. During the last historical eruptions in the Canary Islands (1909-Chinyero in Tenerife, 1949-San Juan-La Palma, 1971-Teneguía-La Palma, 2011-2012-Tago-El Hierro and 2021-Tajogaite-La Palma), tourist activity has developed in parallel to the eruptive process, so that the tourist attraction of these eruptions is unquestionable. In 1909, trips were even organised for the curious and tourists to witness the eruption of the Chinyero volcano in situ. On this matter, a university professor showed his interest in on-site studying the volcanic activity, the Cabrera Pinto High School at the town of La Laguna organised a trip to watch the eruption, and several boats were chartered to take tourists from outside of the island. All this social and cultural phenomenon was also registered by the pictures of the time, which were the first photographs to record an eruption in the Canary Islands and the entire country of Spain. This is a unique aspect of the historical Chinyero's volcanic activity that represents a relevant archival tool for conveying the local geographical memory of the islanders, thus complementing the volcano's geoheritage. This interest can be leveraged further through systematic efforts to document and communicate the characteristics of the resulting geosites. Therefore, this new inventory of Chinyero's volcanic geoheritage can serve as a key reference to advance geotourism activities at and around the volcano.

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Inventory and evaluation of the geoheritage at the municipality of Ansião, Portugal

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Located in the Sicó Massif (western-central Portugal), a karst region known not only by its cultural landscape but also by being partly inside the Natura 2000 European network of protected areas, Ansião is a small municipality with 179 square kilometers and a resident population of nearly 12,000 inhabitants.

Less known is the geoheritage of Ansião, which is currently under study by a private company which is developing a project financed by the Ansião city council. This study aims to identify and evaluate the geoheritage of this territory. This project will allow a basis for protection, valuation and promotion of the geoheritage in this municipality, allowing also to implement practical and critical measures for sustainable territorial management at municipal level. At the end of this project, some proposals will be presented to the city council concerning the protection, valuation and promotion of the geoheritage and the cultural heritage of geological interests of the municipality, allowing the inclusion of these values in the current process of designation of part of this area as a protected landscape.

Preparatory fieldwork has already begun and findings have started to be done, allowing the understanding of how under-discovered is the geoheritage of Ansião and some of the problems related with their analysis and challenges that have to be faced.

These projects, developed at municipal level, and covering all the existing territories at this level, are very rare in Portugal. The majority of them are related with the Portuguese UGGPs, and rarely with municipalities outside of them. Promoting this kind of projects in all the municipalities of Portugal is considered a crucial step to have a basis not only for territorial management but also to other activities that valuate geoheritage, like geotourism, assuming themselves as a source of local and regional development.

Figure 1. An example of the karst landscape of Ansião. There is a strong contrast between the agricultural fields and the mountain areas.

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Tools for the management and planning of the landscape and agricultural spaces of the Orígens Geopark

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Introduction

The climate emergency we are facing needs to be addressed as soon as possible. The response given to this issue has been a significant and rapid increase on the generation of energy from renewable sources. This situation has triggered rural areas, such as the Orígens UNESCO Global Geopark (UGGp), that have received many applications for the implementation of macro-projects of renewable energies in its territory. Specifically, the solar farms proposed cover an area of 600 ha concentrated in an east-west strip of the central part of the UGGp (Figure 1).

The lack of planning regulating this type of activity in rural areas and the non-involvement of rural communities into the discussion creates tension within these communities [1] and potentially put at risk our valuable territories and their sustainable local development due to the denaturalization of landscapes and their impact over the natural and cultural heritage. In addition, they influence and promote the loss of identity and the devaluation of our territories.

The Orígens UGGp is located in the northeast of Spain, in the province of Lleida in Catalonia, 200 km northwest from Barcelona and it is made up of 19 municipalities with 16,405 inhabitants. Its territory has a population density of 8 inhabitants/km^2. However, 13 of the 19 municipalities have less than 5 inhabitants/km^2. The demographic development over the last 50 years has been characterized by a decreasing population.

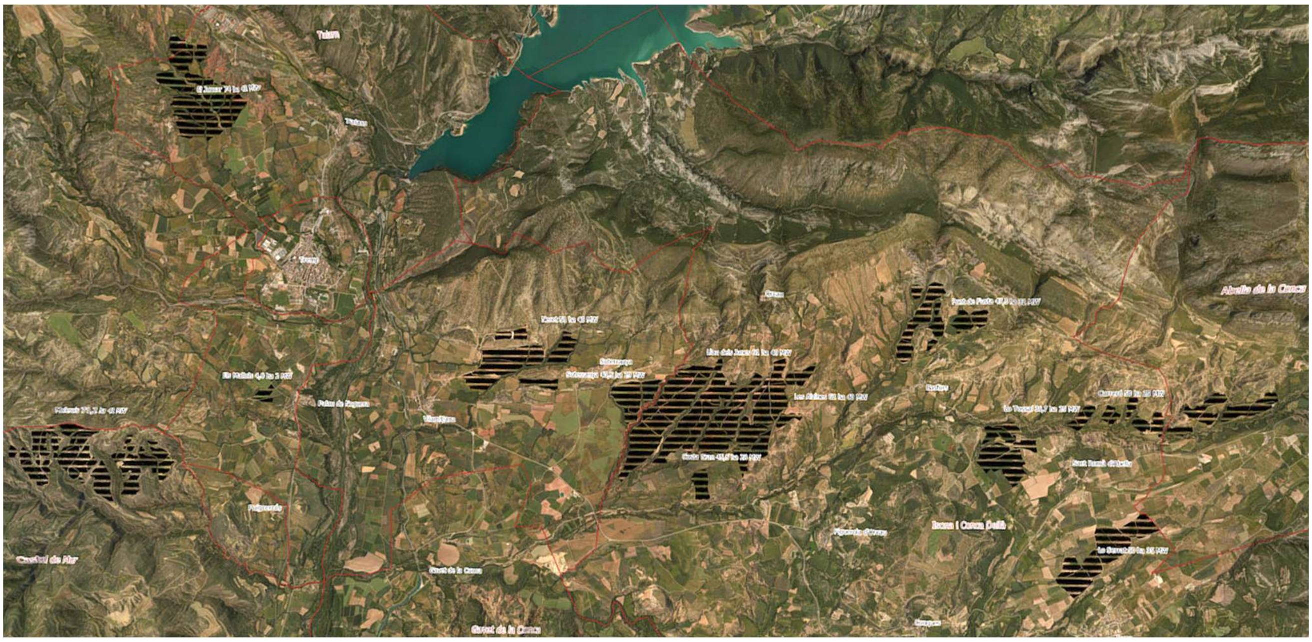

Figure 1. Solar farms projected (black line pattern) cover an area of 600 ha concentrated in an east-west strip of the central part of the UGGp.

Methods and results

The UGGp, at the request of its general assembly members, commissioned a study to develop and propose a series of guidelines for the preservation of the landscape and agricultural spaces [2]. This study establishes the criteria for evaluating new projects and in this way regulates the changes and potential impacts, with the objective to prevent negative effects that may compromise sustainable development of the territory.

The UGGp territory was characterized according to landscapes to be protected and managed and identified highly anthropized or degraded areas as priority areas for the development of new activities with high landscape impact. Zoning values were established to define regulatory parameters to obtain guidelines for the development and integration of new activities in the territory while ensuring sustainable development.

Zoning involved defining protected, vulnerable and high visual exposure areas (Figure 2) using official and local data provided at municipal level in a participatory process. These data included: regional and local geosites outline, Natural Protected Areas (Natura 2000), Local Protected Areas, Special Protected Areas related to fauna connectivity and agricultural value, and Regional Landscape Protected Areas. Zoning also involved identifying areas vulnerable to erosion, wildfires and flooding. Furthermore, visual impact was zoned using landscape viewpoints, georoutes, significant heritage sites and main roads to produce a map with the visual impact in several degrees, from low to very high.

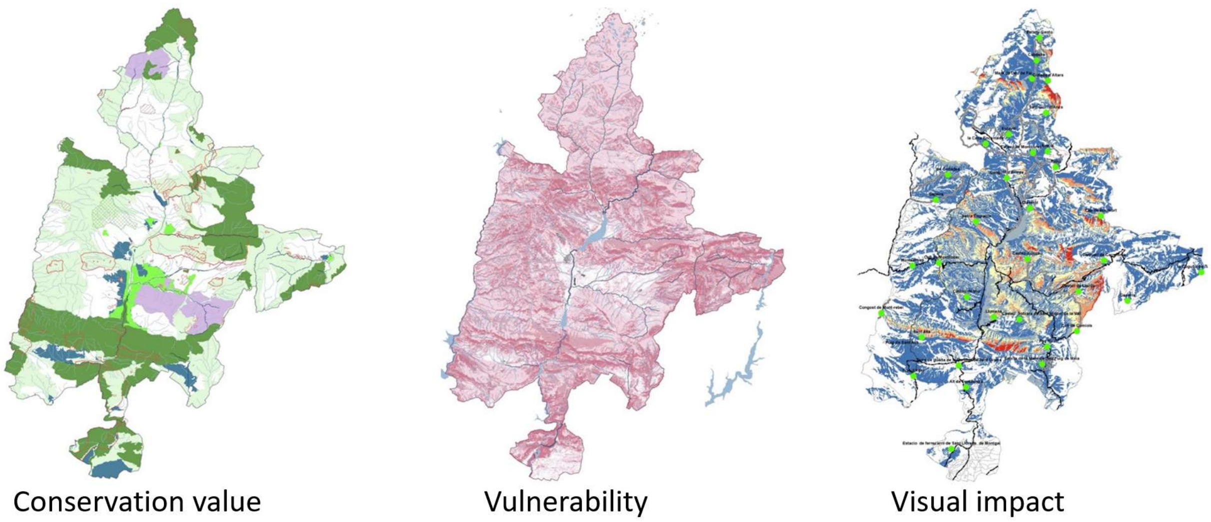

Figure 2. The combination of conservation, vulnerability and visual exposure maps permitted defining areas to be protected and managed and identified highly anthropized or degraded areas as priority areas for the development of new activities with high landscape impact.

The combination of these three datasets permitted identifying areas to be protected, areas to be managed and areas that could be promoted for the installation of solar farm operations. Areas to be protected are areas that, due to their natural heritage, landscape values or vulnerability, require an appropriate degree of protection to prevent their degradation or trivialization. In these areas the construction of buildings or infrastructures unrelated to agricultural, livestock, forestry or natural activities was considered not compatible. Areas to be managed are areas with a low or medium degree of vulnerability, visual impact and agricultural production. In these areas, guidelines for land use planning were established throughout thirty five regulatory parameters, some of which are a maximum surface transformed into facing plots of 10 ha and a minimum distance to dwellings of 1 km. Highly anthropized or degraded areas were identified as priority areas for the development of new activities. These are urban and industrial areas, abandoned extractive activity sites or disused agricultural land. The priority is to promote restoration for agricultural use or naturalization.

Aiming to help on the implementation of these criteria, the UGGp produced an online viewer directed to municipality and County Council staff, so they had at hand all the necessary layers of information and elements to evaluate objectively new development projects or building permits requested in their demarcation. This online viewer includes: UGGp inventories; thematic maps resulting from the study of landscape protection, management and planning; regional planning datasets; areas characterized as natural protected spaces; threatened habitats; urban planning and land registry datasets and the reference topographic and orthophotography maps.

The online viewer access is restricted by password and a confidentiality agreement signed by all users aiming to protect confidential geoheritage sites, such as paleontological sites vulnerable to plundering. Access was provided to technical staff of twenty-two public entities with legislative capacity over the territory.

Discussion and conclusions

This study was approved by the UGGp general assembly in 2022 and is the basis of local planning since the municipalities of the territory incorporate it into their planning regulations. The report and the online viewer integrates different aspects of the landscape necessary to contribute to decision-making in planning for sustainable management and fulfills the ultimate goal of the Geopark: to prevent negative effects that may compromise the sustainable development of the territory.

Although the development of large scale solar farms in the territory benefits the Sustainable Development Goals (SDGs) promoted by the United Nations, such as having affordable and clean energy (SDG 7) or climate change mitigation (SDG 13) it also goes against promoting decent work and economic growth (SDG 8), reduce inequalities (SDG 10), having sustainable cities and communities (SDG 11) or endorsing responsible consumption and production (SDG 12). The solar farms projects covering over 600 ha of agricultural land would diminish food production and reduce agricultural activities in the area while their impact on the landscape would hinder tourism attraction.

The sustainability of any project is a fundamental criterion whose non-observance is always the source of greater poverty or exploitation for the territory and its local population. Rural territories are not renewable and protecting them from large industrial activities is key to their sustainable development.

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SESSION 3: URBAN GEOHERITAGE AND GEOCULTURAL HERITAGE

Convener: Laura Melelli

Rocks in the Street: Representation of Andorra's geodiversity

Gallego N., Margalef A.

Narrating the history of a territory through its geological and geomorphological heritage: an itinerary between Chiavenna and Piuro (Central Alps, Lombardy)

Arrigoni F., Pigazzi E., Tantardini D., Colzada G., Marinoni A., Apuani T., Tartarotti P.

From the local geodiversity to a database: The PCTO titled "Conoscere la Geodiversità"

Brustia E., Pompili R., Primerano P.

My village, my fossil: an operation to reconnect inhabitants and their geoheritage

Vautrin Q., Biot V.

Benefits of urban geoheritage for geotourism, education, and identity in cities

Vegas J., Díez-Herrero A.

"Gravine" canyons, amazing windows on urban development and geology. Examples from the rupestrian towns of the "Terra delle Gravine" regional park (Puglia, Southern Italy).

Venezia V., Bellini F., Festa V., Sabato L., Tropeano M.

The challenge of geological and cultural heritage conservation in urban areas

Bentivenga M., Pescatore E., Palladino G., Giano S.I.

Rocks in the Street: Representation of Andorra's geodiversity

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In May 2007, the open-air museum "Roques al Carrer" (Rocks in the Street) was established in Andorra la Vella, the capital of the Pyrenean country Andorra, with the aim of promoting the values of global geodiversity [1] and the geological heritage of Andorra through the observation and study of elements belonging to our daily life.

This museum Rocks in the Street was divided into three parts: the Rock Garden, with big rocks of all types that can be found in Andorra, accompanied by explanatory panels; the Geological Itinerary, with more than thirty panels in several streets of the capital of Andorra, explaining the ornamental rock used in the facade of the different buildings and providing explanations related with geology; and the Granit Architecture Itinerary, showing ten buildings which represent the granite architecture and highlighting its key characteristics and its importance in the Andorran context.

In May 2024, the museum was completely renovated and updated:

- The Rock Garden [2] was moved to the Sorteny Valley Natural Park [3], a new location no longer in the city but in the mountains, with the same aim of offering in a single place a representation of all the rocks that outcrop in Andorra. The Rock Garden (figure 1) is currently located next to the botanical garden of the Sorteny Valley Natural Park, in the middle of an easy mountain trail within the Natural Park, which many tourists of different ages and backgrounds and even schools from the country access.

  The Rock Garden is accompanied by a series of panels which will allow the visitor to learn more about rocks in general, rocks in Andorra and some of their uses. We have several examples in Andorra, such as Romanesque architecture or granite architecture. Another of the most significant examples in Andorra is the art of dry stone [4] that is illustrated in the Rock Garden situated in Sorteny (figure 2).
- The Geological Itinerary in the streets of Andorra la Vella (figure 3) was closed, as it was very difficult to keep up to date with the constant changes of shops and their facades. Despite this fact, it is an itinerary that can be adapted to other streets and cities of the country, in case of future interest of another city council.
- The Granite Architecture Itinerary [5] was maintained in the old town of Andorra la Vella (figure 3), since these are buildings that have not undergone any modifications, and the city council of the capital of Andorra wishes to continue to show this architectural style which began in the 1930s, lasted until the 1960s and was very important in Andorra.

Andorra Research and Innovation will continue to review and update the museum Rocks in the Street, currently formed by the Rock Garden in the Sorteny Valley Natural Park and the Granite Architecture Itinerary in the streets of Andorra la Vella, both designed to introduce people into the always interesting world of geology, and the Andorran geodiversity.

Figure 1. The current Rock Garden, located in the Sorteny Valley Natural Park, in Andorra.

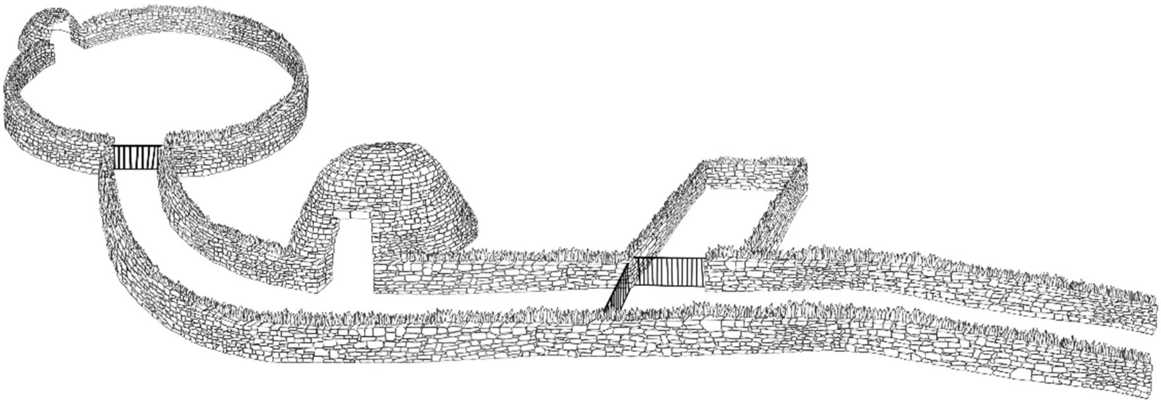
Figure 2. Illustration of an example of dry stone construction used for cattle breeding in Andorra.

Figure 3. Pictures of two panels of the Geological Itinerary, explaining geological concepts of the ornamental rocks of the facades of some buildings in Andorra la Vella, and of one panel of the Granite Architecture Itinerary, also in Andorra la Vella.

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Narrating the history of a territory through its geological and geomorphological heritage: an itinerary between Chiavenna and Piuro (Central Alps, Lombardy)

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Since prehistoric times, Alpine valleys have witnessed the growth and development of populations that progressively learned to exploit their natural resources and features, while also dealing with the many natural hazards that these territories present. Traces of this interconnection can be found throughout the entire Alpine chain, the study of which helped us to better comprehend the evolution of the populations that inhabited these areas until present-day.
Looking at the Central Alps, the area around Chiavenna and Val Bregaglia (Lombardy, Sondrio Province) represents a place where geological, historical and cultural heritage are inextricably intertwined, well predisposing to a geo-cultural narrative of the area. Chiavenna was raised within the homonymous valley that, since Roman ages, served as an important connection with the northern European regions. The oldest traces of human passage through the valley passes date from pre-historic Mesolitic ages, while the earliest evidence of stable human fruition trace back to Late Bronze and Early Iron Ages [1], with proof of soapstone extraction from the lower southern flank of Val Bregaglia and its processing, an activity that reached its maximum development between the XV and XVII centuries A.D., until an almost total abandonment of the quarries in the XX century A.D. [1]. Soapstone is a commonly used term to indicate talc-schists, metamorphic rocks rich in talc, that in this area lie embedded inside the ultramafic rocks of the Chiavenna Unit [2]. The petrographic features of soapstone are responsible for its good workability and predisposition to the production of everyday objects as pots and vessels, as well as construction and decorative material, as witnessed by dozens of monuments and architectural elements that can be found in historical buildings in the valley. Around Chiavenna, recent surveys [1] reported 35 open pit quarries and 46 underground quarries, locally called "*Trone*", most of them scattered at the junction between Valchiavenna and Val Bregaglia. When not directly visible, the presence of underground soapstone quarries is indicated by several engraved boulders, which acted as markers to identify and reach the sites, as well as to indicate their owners. Hundreds of rock engravings are documented in the area, covering a time range of almost two millennia. The best-preserved quarrying example is the renowned *Càurga* (local term that is usually related to a deep gully), the biggest soapstone quarry in Chiavenna that dates back to Roman ages. Here, the soapstone extraction left a dozen meters-high incision in the peridotitic rocks on which archaeo-botanical Paradiso Park stands. Inside the park, various archaeological and historical remains surrounded by a variety of botanical species are preserved, perfectly embodying the coexistence of biodiversity, archaeology and cultural heritage. The park is developed on a peridotitic relief that rises enigmatically in the middle of the valley, bearing witness to a complex and prolonged geological evolution.
Furthermore, the slope behind Chiavenna shows evidence of gravitational collapses that have involved large portions of the valley flank and, over millennia, have reached and occupied the valley floor with large landslide bodies. These phenomena are among the most impacting factors in the past and present-day landscape evolution of this territory. The communities that inhabited the valley learned to take advantage of these mass-wasting phenomena, for example, occupying the raised morphologies created by their deposits that offered shelters from flood events. At the same time, the circulation of air at constant low temperatures through the year (the so-called "*Sorél*") within the crevices among the blocks allowed the use of landslide bodies as cellars, leading to the development of "*Crotti*", a distinctive - almost unique - feature, representing a natural refrigeration system for storing food and wine.
But the cohabitation between humans and natural evolution has not always been peaceful, as in the case of the catastrophic Piuro landslide that in 1618 completely erased the ancient village [3]. Piuro is located a few kilometres east of Chiavenna, and during the XVI and XVII centuries became a rich and renowned trading

centre, where soapstone manufacturing played a central role. Today, the remnants of this ancient village are gradually unearthed thanks to active archaeological excavation sites that, together with several other sites of interest – such as the Piuro Archaeological Museum or the splendid Renaissance Vertemate-Franchi Palace – preserve tangible evidence of a place that no longer exists. In order to stimulate the perception of vulnerability to natural hazards and to permit observation of the interactions between natural and anthropic processes transforming the landscape, illustrative and descriptive panels have been installed near the main sites of interest (Figure 1).
Another major factor that reshaped the valley landscape was the ice flow of Pleistocene glaciers flowing from the Engadine area, that in thousands of years carved and modelled the valley flanks, leaving behind, after the retreat, lots of glacial landforms and deposits [4]. Hundreds of subglacial forms consisting of potholes and mounded rocks are still very well preserved in the Marmitte dei Giganti Park, a regional natural reserve that extends between Chiavenna and Piuro.
All these coexisting elements allow for a 360-degree view of the geological and cultural history of the territory, not treating each aspect as a single entity, but rather as part of a single overall vision. Several projects for the study, conservation and promotion of these sites took place over the years, with the participation of the Earth Sciences Department "A. Desio" of the University of Milan, which has been working in this area for more than twenty years. Among the most recent, the A.M.AL.PI.18 project (Italian acronym for "Moving Alps, and Movements in the Alps"), aims to encourage an innovative strategy for the promotion of natural and cultural heritage in the Alpine area comprised between Maloja and St. Gotthard, connecting sites which have experienced important geomorphological and anthropic changes due to the occurrence of landslides of great social impact. This project significantly contributed to the study and diffusion of knowledge of the main landslides of the Alps, with special attention to the Piuro landslide. Among the main products of the project stands the AMALPI Trek, a geo-cultural hiking trail between Italy and Switzerland that passes through Val Bregaglia, touching several landslide sites and narrating their features and their stories, but also offering interesting connections with the other local geo-cultural themes previously described, thanks to the help of a dedicated hiking guide [5].
Treading the path of the AMALPI Trek, this work wants to present and promote a one-day and easily accessible geo-itinerary between Chiavenna and Piuro, along which the visitor can draw information from the geo-cultural sites encountered along the way, learning about the territory on several intertwining thematic levels (Figure 2). Our geo-itinerary starts from Chiavenna Railway Station and passes by the *Càurga* and the archaeo-botanical Paradiso Park. From here, it reaches Piuro passing through the Marmitte dei Giganti natural reserve, where some subglacial forms and "*Trone*" can be visited. In Piuro, the geo-itinerary touches several sites that witness the catastrophic 1618 landslide and then passes by the natural monument of Acqua Fraggia Waterfalls reaching the western fraction of Piuro and the Vertemate-Franchi Palace. Finally, it returns to Chiavenna along the Mera River, passing through the "*crotti*" area. The itinerary is 12 km long, covers a difference in level of 350 m and can be covered by a normal hiker, without any hurry, in about 8-9 hours.
The huge geo-cultural heritage available in the area between Chiavenna and Piuro represents an excellent way to promote the territory and its story, merging geology, history and culture in a fascinating journey that started millions of years ago up to the present day. Visitors will be encouraged to witness the intimate relationship between geology, territory and population, visualizing how the historic and cultural evolution of a society can be controlled, first and foremost, by the geological predisposition of the territory. The proposal of this geo-itinerary is intended to be a virtuous example of promotion, dissemination, fruition and conservation of the local geo-cultural heritage, through a series of installations and infrastructures that stimulate local geo-tourism, proposing itself as a sustainable source of growth of a local reality. The setting up of a geo-itinerary of this kind could also support alternative and effective ways of teaching the local culture to schools and to disseminate this knowledge through the population. This kind of approach could constitute an example for applications in other areas, especially along the Alpine chain, where geology and man had a closely related evolution that deserves to be acknowledged and appreciated.

Figure 1. Examples of illustrative-descriptive panels installed in the area of the Piuro 1618 Landslide.

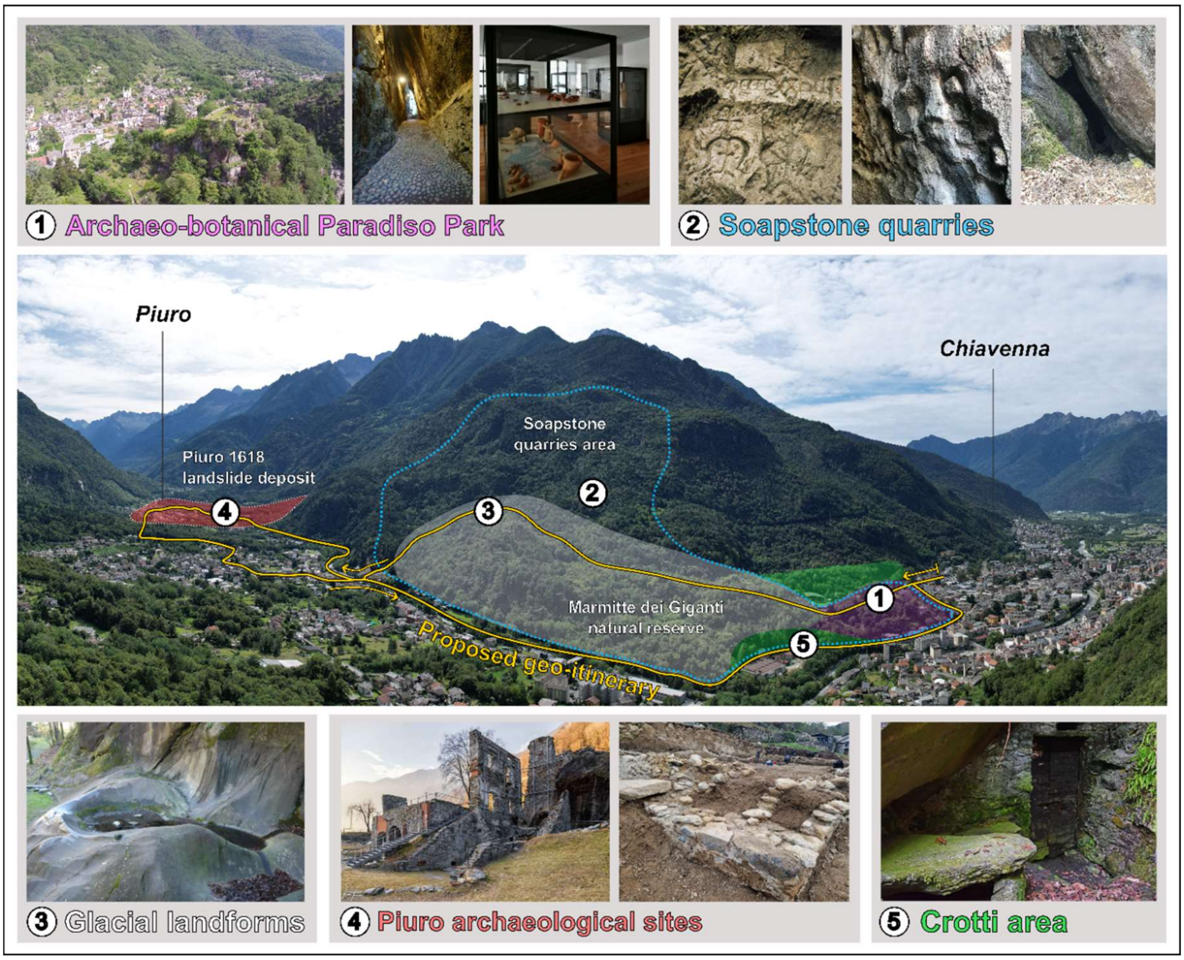

Figure 2. Panoramic view of the southern flank of Val Bregaglia. The proposed geo-itinerary runs between Chiavenna and Piuro and passes through a wide variety of geoheritage sites, indicated in the boxes.

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From the local geodiversity to a database: The PCTO titled "Conoscere la Geodiversità"

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Within the framework of the initiatives and activities for the dissemination of the Earth sciences knowledge promoted by the Geological Survey of Italy in recent years, there has been a significant increase, and among others, the topic of Geological Heritage has proven to be an area that sparks interest and curiosity. The dissemination has been developed through lessons and workshops at primary and secondary schools, seminars, and excursions.

In the 2024-2025 academic year, a PCTO (Paths for Transversal Skills and Orientation - educational pathways aimed at guiding students in their final three years of secondary school towards the world of work, further studies, and the development of transversal skills) project titled "Conoscere la geodiversità" has been proposed.

The program involves 7 students from Liceo Darwin in Rome (RM) and 8 students from Liceo Ramadù in Cisterna di Latina (LT), from the 3rd, 4th, and 5th years of high school, and will have a total duration of 30 hours; it aims to introduce secondary school students to the fundamental concepts of geodiversity, its conservation, and the enhancement of geological heritage, with a particular focus on geosites, through the exploration of the National Inventory of Geosites hosted by ISPRA. The project will involve students in creating a georeferenced database using QGIS, an open-source GIS software, which is useful to collect and manage data related to the geodiversity of Rome on a local scale. The activity includes two field trips in the city of Rome: the first one near the Parco della Caffarella and Appia Antica, to visit the Nymphaeum of Egeria and the Capo di Bove lava flow outcrop at the base of the Tomb of Caecilia Metella, and the second one in the centre of Rome, to discover the geodiversity of the city and the relationship between geology and urban development (Pantaloni et al., 2023). The itinerary starts at the Basilica of San Clemente, following Via dei Fori Imperiali from the Colosseum to the Rupe Tarpea cliff at the SW border of Campidoglio Hill, to directly gather the necessary data about geodiversity. Additionally, students will learn to use programming languages and geographic information systems (GIS), acquiring practical skills in a mostly scientific context. A GIS project will be set up, using the geology of Rome as a base map, georeferenced by the students themselves. The project will include a database structured like the National Inventory of Geosites, which will also be accessible via smartphone through the QField application. The goal is to raise awareness among participants about geodiversity, providing them with concrete tools for the informed management of local geological heritage.

During the classroom lessons, topics related to geodiversity, geological heritage, and the close correlation between geological aspects with human life and urban evolution are developed and presented. The use of GIS tools is useful for creating the "school" database that is then taught. After georeferencing the geological map of the area of interest onto the topographic and road maps, a table is created to be used in the field for characterizing the geosites that will be identified, collaboratively choosing the fields necessary for a complete and representative characterization of the geosites, such as the name of the geosite, type, geological characteristics, and photos, which are essentially the data for the inventory.
In the final lessons, the data collected during the field trips are entered or refined through the QGIS software and shared in the QField app, which makes the inventory accessible (and updatable) even from smartphones.

An alternative, user-friendly application that is demonstrated to the students is Google Earth, which allows for the creation of a project through the addition of points of interest, including the insertion of photos or videos and descriptions.

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My village, my fossil; an operation to reconnect inhabitants and their geoheritage

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There can be a real gap between the palaeontological richness of an area and the way local people perceive it. Raw scientific knowledge can easily appear abstract, complex and, ultimately, of little interest to local people. That's why it's vital to promote our geoheritage through scientific outreach. More than 700 fossil species have been found in the *Causses of Quercy*, an area internationally well-known by palaeontologists [1, 2, 3, 4]. However, the region's inhabitants are largely unaware of the importance of their territory and the geoheritage they encounter on a daily basis, especially since many of the discoveries were made decades ago. Some know that fossils have been discovered, but not really to whom they once belonged.
The Causses du Quercy UNESCO Global Geopark has therefore launched the "*Mon village-Mon fossil*e" (My village-My fossil) initiative to raise awareness among local residents about some of the region's geoheritage. As part of this project, which combines art and science, seven statues of prehistoric animals were erected in seven villages in the geopark. These statues were not chosen at random, but represent seven animals named in honour of the village where they were discovered. All the statues are accompanied by explanatory panels, describing the animal, its environment and period, as well as anecdotes.
This work was carried out with the municipal staff. Throughout the project, they were proud to discover the international scientific renown that these fossil species brought to their commune, and to know that their village had witnessed a scientific discovery.
The statues were placed in strategic locations, such as village squares, parking lots and churches. These animals, once completely unknown and abstract to the townspeople, are now familiar and instantly recognizable figures.
«*Mon village, Mon fossile*» is a growing project. Other statues are in the pipeline, and as part of the Geopark's tourism strategy, events are regularly organized around them to keep this heritage alive.

Figure 1. a) *Palaeotodus escampiensis*, name inspired by the commune of Concots; b) *Peratherium lavergnense*, name inspired by the Lavergne district in the commune of Concots; c) *Bachitherium guirounetensis*, name inspired by the commune of Bach.

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Benefits of urban geoheritage for geotourism, education, and identity in cities

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Most cities and municipalities have geoheritage within their urban and neighborhood areas as a new resource to offer another form of tourism. Geological resources may be located in public spaces, parks and gardens, and private spaces inside courtyards and homes. Urban geotourism has five basic features that make it a promising new niche tourism [1]: i) It diversifies the offer of tourism in cities with new and surprising elements, and unexpected experiences; ii) It supplements the traditional offer, maximizing its appeal and increasing the length of time in overnight stays; iii) It is there all year round, prolonging the traditional offer in certain seasonal periods (winter in the interior) and at certain times of day (dawn, midday and dusk); iv) It is an alternative in the absence of historical and artistic resources in new neighborhoods and surrounding zones, distributing tourism and any resources generated more widely; and v) It is accessible and universal to everyone, as most of the heritage outcrops are in public places in the open air. Therefore, their visit and enjoyment do not represent a cost; they are free to access and in equal conditions for all potential visitors.
In addition, urban areas are natural laboratories for formal and informal education. The benefits and values of urban geoheritage are significant for the citizens themselves:

- The city’s geology signifies its identity as iconic landscapes and unique rock landforms.
- Urban geology is linked to knowledge of the planet: a fantastic Earth history.
- Confluence with other heritage types (historical, religious, traditional trades, legends, etc. with a geological background).
- Raising awareness of the major environmental crises and challenges facing society.
- An opportunity for holistic nature conservation.
- Increasing the well-being and health of millions of citizens living in urban environments.

The fact that this geoheritage is located in public spaces also guarantees greater accessibility for people with disabilities, as opposed to the geoheritage in protected natural spaces or in rural areas that are much more difficult to access, where many of the routes are not accessible to these people. However, this heritage in urban settings is more fragile and vulnerable as it is subjected to greater pressure and impact. Pollution, civil works, urbanization, and, in short, the occupation and management of public spaces, demand the promotion of best practice guidelines to guarantee their conservation and the legacy of the future [1]

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"Gravine" canyons, amazing windows on urban development and geology. Examples from the rupestrian towns of the "Terra delle Gravine" regional park (Puglia, Southern Italy)

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In the western sector of the Murge area (Puglia Region, Southern Italy) several towns developed their inhabited area "inside" carbonate soft-rocks cropping out along flanks of canyons locally known as "Gravine" (plural; singular: "Gravina"). These rocky valleys allowed (and still allow) the inhabitants to live in very articulated caved houses characterized by a "negative" architecture, i.e., with rooms, arches, pillars, ornaments, friezes, and more realized by digging the rock mass and building only facades.
The existence of these rupestrian towns was possible because the opportunity to cave houses was coupled with the presence of water in the upper part of rocky valleys and the development of freshwater management systems based on channels and tanks dug in the same rocks, even collecting rainwater. Urban settlements show an architectural structure based on such systems, resulting therefore perfectly integrated with the natural resources given by the geological and geomorphological context. Therefore, "Gravine" canyon and rupestrian towns give us a glimpse on the man-environment relationships particularly explicative for educational and geotouristic purposes. These features are here well addressed in "natural" geological sections and show how anthropic choices and solutions are constrained to a unique geological context.
Several examples of different human settlement located in the "Terra delle Gravine" regional park will be shown and will provide a favourite and unique point of view of how the anthropization and geological context express a kind of culture spread all over a wide territory being a worldwide important geoheritage feature to be preserved for future generations.

The challenge of geological and cultural heritage conservation in urban areas

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The topics addressed in this study concern the protection and enhancement of the geological and cultural heritage present in urban areas, which are essential for improving and spreading their knowledge. Geo conservation includes a series of issues related to scientific, technical, administrative, educational and political contexts [1] [2] and actions dedicated to i) pure and applied research, ii) protection of geological-cultural heritage, and iii) and the enhancement and sharing of knowledge about sites of interest. This paper shows sites of geological-cultural interest, connected with urban areas in the southern Apennines (Fig. 1), which need to be subject to geoconservation actions to ensure proper valorisation and management [3] [4] [5].

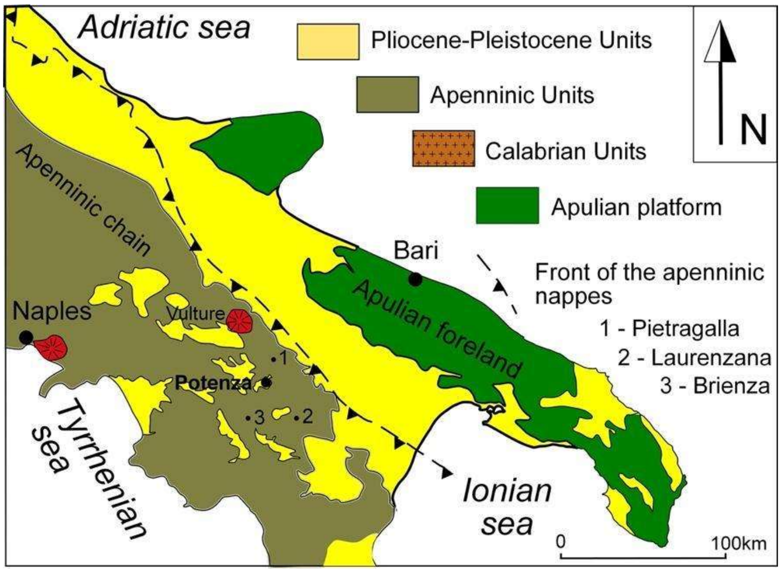

Figure 1. Sketch map of the southern Apennines with the location of the three studied sites [2].

1) Pietragalla

The area including the Pietragalla Town is characterized by geological units forming the frontal portion of the Southern Apennine thrust belt: i) The Lagonegro Units are represented by the Flysch Rosso Formation (Upper Cretaceous-Oligocene), made up of alternating red shales and limestones and the Numidian Flysch (Aquitanian-Lower Langhian), made up of alternating medium-coarse grained quartzarenites and brown clays; ii) The Irpinian units represented by the Serra Palazzo Formation (Langhian-Tortonian) which consists of sandstone, lens-shaped microconglomerates, calcarenites and clays; iii) Pliocene thrust top deposits, consisting of clays, medium to coarse grained sands, sandstones and conglomerates unconformably overlying on the previous units. These units were variously affected by the compressional tectonics from the middle Miocene to the middle Pleistocene. Plio-Quaternary NW-SE oriented extensional faults commonly overprint the older contractional structures. The town of Pietragalla was built on Numidian Flysch deposits.

The Palmenti, included in the regional and national list of geosites, occur along the eastern slopes of the Pietragalla Hill at an altitude of approximately 775 m a.s.l. and are dug into the quartz-rich sandstones pertaining to the Numidian Flysch. The palmenti are a complex of structures representing a particular type of rural architecture linked to winemaking activities (Fig. 2a, b). After the harvest, the grapes were pressed and the must was partially fermented in the palmenti. The palmenti were built next to each other and developed at various levels along the slope. These structures were covered with soil, which encourages the growth of wild herbs to ensure that the artefacts blend in with the surrounding landscape. Each palmento is composed of an external part, built in masonry with elements of the same rock excavated to create the tanks, a door and a slit useful for ventilation of the room. Inside the palmenti there may be from one to four tanks for pressing the grapes and fermenting the must. More common are the palmenti made up of two tanks for pressing and two for fermentation, one was used for white grapes and the other for red grapes that were often used by several families. After fermentation the must was drawn off and transported to the cellars, located in the historic center and along the north-facing slope of the Pietragalla hill (Fig. 2c)., to be poured into wooden barrels. The palmenti were excavated during the 16th century and in the following three centuries, and consist of pressing and fermentation tanks, connected to each other by drainage channels for transporting the must and cavities for housing containers. In the period between the 18th and 19th centuries, the 'little house' was added, that is, the elevated structure covering the tanks and the hypogeal spaces. Most of the palmenti were used until the 1960s, while only a few are currently kept active. In recent years, the municipal administration has started a process of recovery and enhancement of the site by organizing events that have made the citizens of Pietragalla more aware of the value of the palmenti and cellars (Fig. 2d).

Figure 1. a) aerial view of the palmenti; b) palmenti; c) “CantinArte” event; d) cellars in the urban area of Pietragalla.

2) Laurenzana

Laurenzana is located in the central-eastern sector of the Southern Apennines, near the front of the chain. In the study area, the outcropping terrains pertain to the Sicilide and the Sannio units. These terrains constitute the pre-Miocene substratum for the thrust-top deposits, the Irpinian and Plio-Pleistocene units, represented by the Upper Langhian - Lower Tortonian Gorgoglione Formation (turbiditic clayey, arenaceous and conglomerate successions), and by the Calvello Basin deposits (marine to transitional deposits) respectively. The, Sicilide Units, represented by the Corleto Perticara Formation, which consists of marls, marly limestones, calcilutites, calcarenites, shales and, less frequently, sandstones and calcirudites, regionally overthrust onto the Gorgoglione Formation. Along this tectonic structure, conglomeratic slices of the Gorgoglione Formation are found, forming the natural towers used in the medieval time to build the Laurenzana Mother Church and the Castle. The area is delimited by two strike-slip fault zones: a NE-SW oriented right-lateral strike-slip zone which corresponds with the Camastra Stream and a WNW-ESE oriented left lateral strike-slip zone, known in literature as the Scorciabuoi Fault. N 110° oriented left-lateral strike-slip faults and SW-NE oriented normal faults represent the latest tectonic stages of the area. The south-western conglomeratic tower, (855 a s.l.),

was chosen to build the medieval castle whereas the north-eastern one (820 a s.l.) hosts the Mother Church. The Laurenzana Castle is well integrated with the underlying rocks (Fig. 3a). Designed for the defense of the village, its walls follow what in military jargon is called the "tactical edge of the terrain", strengthening the natural defenses of the rock and, at the same time, making full use of the available space, as can be seen from the plans of the two buildings. The underground rooms used as stables and cisterns are developed on two floors all dug into the rock. The castle dates back to the Norman period, when it was enfeoffed to Guglielmo son of Matteo da Tito and was subjected to a major renovation during the Angevin period (1250-1450). Subsequently, the Aragonese (1400-1500) significantly modified the structure of the building to adapt it to firearms and the new Renaissance taste. Between the eighteenth and nineteenth centuries, it took on its current appearance characterized by a palace shape, and no longer a defense. The building grew increasingly tall on all sides and expanded by exploiting other small spaces still available at the top of the tower. In this period numerous collapses were reported that affected the perimeter of the tower and at the same time the first works were carried out to counteract the damage, such as the buttresses. In the first decades of the twentieth century the castle began to be abandoned, undergoing a sharp acceleration in the post-war period. In the eighties, a major recovery activity began. The works first involved the consolidation of the conglomerate tower and then the buildings above.
The Mother Church of Santa Maria Assunta was built at the beginning of the 13th century and enlarged in 1583 (Fig. 3a). It took on its current form in the 18th century when the lateral chapel, completed in 1780, was added to the basilica plan with three naves. The monumental double-ramp entrance staircase with an oval plan, the main portal and the secondary portal are late Baroque. From the 1980s to today, the Mother Church of Santa Maria Assunta has first undergone works that made the building earthquake-proof and then numerous restorations that have emphasized its historical and artistic value.

3) Brienza

The area is located in the central-western portion of the Southern Apennines chain and corresponds with a major thrust that determines the superposition of the Apennine Carbonate Platform onto the Lagonegro Basin units [3]. The platform succession consists of Triassic dolostones and dolomitic breccias passing upwards to Ellipsactinia Limestones (Malm). Miocene sandstones, pertaining to the Monte Sierio Formation, unconformably rest on the previous lithologies. The Apennine Carbonate Platform deposits are tectonically superimposed onto the youngest Lagonegro Units represented by the Flysch Rosso Formation (Upper Cretaceous-Eocene). This formation consists of turbiditic calcarenites alternating with red to green coloured marls. Above the Mesozoic substratum, in angular unconformity, lie the Pleistocene alluvial deposits pertaining to the Pergola-Melandro intermountain Basin. This latter basin is filled up with an alternation of reddish matrix-supported polygenic conglomerates and coarse-grained yellowish sands that reach a maximum thickness of about 100 m. The thrust plane consists of a top to E-NE articulated surface. The unit at the footwall shows typical semi-ductile deformation represented by S-C tectonites and boudinage. At the hanging wall the carbonates appear very fractured showing cataclasitic interval with a floury appearance. The thrust contact is repeatedly dissected by younger high angle faults, with a predominantly NW-SE direction. These structures produce the dissection of the original thrust plane and a stepped morphology progressively dipping towards E-NE. Fault activity, indicated by the syntectonic calcite fibres recognized on the fault planes, shows a general transtensive or extensional kinematics. The Plio-Quaternary age of these faults is based on the deformation of the Pergola-Melandro Basin deposits. The thrust plane is exposed near the confluence of the Pergola and Fiumicello streams surrounding the Brenza village. Due to the general uplift affecting the area these streams progressively eroded the alluvial deposits and exposed the Mesozoic substratum generating an asymmetric valley with the steeper side in the correspondence of the carbonates and the gentler side modelled in the more erodible terrains of the Lagonegro Units. Remains of the original alluvial plane are currently visible at an altitude of about 750 a.s.l. forming flat areas or, at margins, a series of very thin ridges with sub-horizontal longitudinal profiles. The repeated episodes of stasis and tectonic uplift were recorded by a series of fluvial terraces located at different heights with respect to the current bed of the Pergola and Fiumicello streams. The whole area shows a typical mountain landscape with the surface hydrography strongly controlled by recent tectonics. The medieval castle of Brienza is located in the correspondence of the carbonates occurring at the hanging wall of the thrust (Fig. 3c).

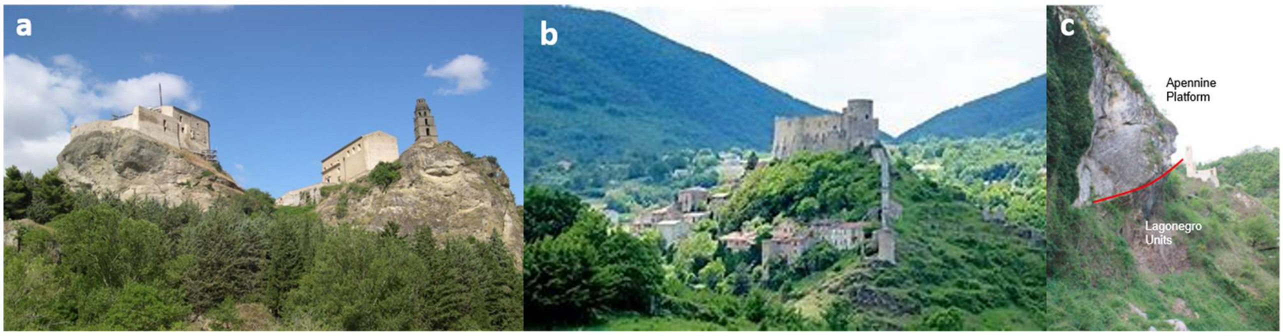

Figure 1. a) castle and Mother Church of Laurenzana; b) castle of Brienza; c) overthrust under the castle.

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SESSION 4: NATURAL AND ANTHROPIC IMPACT ON GEOHERITAGE

Convener: Joana Rodrigues

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INVITED KEYNOTE
Scientific research on geoheritage: a key to sustainable land management and planning

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Scientific research on geodiversity and geoheritage has proven essential to support sustainable land management and planning. Geodiversity and geoheritage are constantly threatened by natural processes and human activities, therefore an effective methodological framework for the assessment of their degradation risk is crucial to guide geoconservation strategies. In recent years, significant progress has been made in geoconservation at both global and national levels. In particular, dedicated efforts such as the UNESCO International Geosciences and Geoparks Programme have significantly contributed to raising awareness and developing protection strategies on geodiversity and geoheritage globally. At a European level, Spain serves as a notable reference for geoconservation, having implemented a solid legal framework that specifically addresses geodiversity and geoheritage, as well as establishing the need for actions aimed at monitoring their conservation status. However, substantial challenges remain; notably, not all European countries have adopted comprehensive national legislation dedicated to the protection of geodiversity and geoheritage. In Italy, despite important national and regional initiatives — including the ongoing creation of a national inventory of geosites — the lack of dedicated national legislation and a shared methodological framework for the assessment of geoheritage degradation risk remain critical obstacles.

In this context, this keynote presents case studies that illustrate the crucial role of scientific research and active stakeholder collaboration in supporting effective management of geodiversity and geoheritage. Moreover, it highlights the need for further methodological advances in geoheritage degradation risk assessment and management. Ultimately, the keynote aims to stimulate a broader discussion on improving scientific approaches, stakeholder engagement and management practices to ensure geoconservation and integration of geoheritage and geodiversity into land planning policies.

Shaping the Alps: two centuries of human influence on the landscape and geoheritage of the Stelvio Pass

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The Stelvio Pass, one of the highest paved mountain passes in Europe (2758 m a.s.l.), offers a significant case study for evaluating the long-term effects of human activity on high-altitude geomorphology and to analyse the evolution of the natural and cultural heritage.

Over the past two centuries, the mountain landscape has been reworked by anthropogenic processes through infrastructure development, military fortifications and ski area construction and evolution. These human-induced alterations have interacted with natural geomorphic processes, influencing slope stability, periglacial dynamics, and sediment transport [1-2].

The Stelvio Pass is also of great importance from a geoheritage perspective. It hosts rapidly retreating glaciers and glacial landforms and periglacial features undergoing rapid change, making it a valuable natural laboratory for studying climate-induced transformations and to analyse geodiversity and geoheritage changes [3]. The area includes one of the most extensive high-altitude karst regions in the Alps and is geologically unique due to the presence of the tectonic contact between the limestone formations and the basement rocks. This peculiar high-altitude landscape and its unique assemblage of geomorphological features, point of interest and identified and potential geosites have also been influenced and modified by human activities. Road construction, military interventions, and tourism development have not only altered the geomorphological processes but have also reshaped the perception, accessibility, and conservation status of the geoheritage. This ongoing transformation raises questions about the sustainability of interventions and the need for balanced management strategies to preserve both the scientific and cultural value of these landscapes.

The road construction in the early 19th century, under the direction of Filippo Ferranti and Carlo Donegani, was a pivotal intervention, altering natural drainage surface systems and modifying erosion rates. During World War I, the Stelvio region became a critical battlefield where trenches, tunnels, and fortifications disrupted sediment transport and slope equilibrium and at the same time generating the historical value of point of interest today promoted and valorised by spectacular thematic hiking trails. The mid-20th century witnessed the rise of ski tourism, with the development of ski slopes, artificial reservoirs, and snowmaking infrastructure, further modifying permafrost conditions and accelerating landform changes [4] (Figure 1).

This study employs a multitemporal approach integrating historical cartographic analysis, aerial imagery interpretation, remote sensing, and field surveys. Historical documents provide insights into past geomorphic conditions, while digital elevation models (DEMs) and high-resolution topographic data allow for the quantification of landscape evolution. Field investigations include geomorphic mapping, sediment sampling, the monitoring of periglacial and glacial features and the effects of tourism activities including trails change.

The findings reveal that human activities have significantly altered the natural geomorphological equilibrium [3]. Road construction modified mass transport processes while wartime modifications introduced structural weaknesses into the landscape. The post-war expansion of ski tourism further exacerbated permafrost degradation, altered hydrological regimes, and contributed to increased sediment redistribution. At the same time human presence has generated a *connubium* between natural and anthropic landscape which evolution is continuously modifying under changing climatic conditions and changing human presence (Figure 2).

The implications of these findings highlight the importance of balancing human activity with environmental conservation. The Stelvio Pass represents a crucial site for understanding the interactions between anthropogenic modifications and natural geomorphic processes in high-altitude sensitive environments. A sustainable management approach is necessary to mitigate the ongoing impacts of tourism and infrastructure while preserving the geocultural heritage of this unique landscape [5].

Figure 1. The old chart representation on the Stelvio Pass in the A) 1637 and B) 1815/1825. C) The main project for the construction of the road (1842).

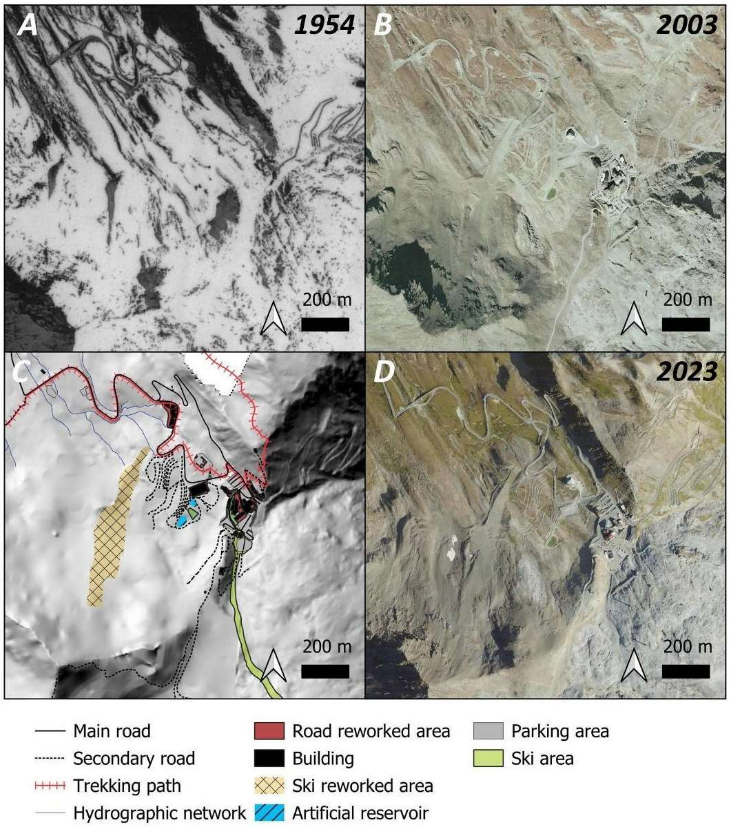

Figure 2. Multitemporal analysis of satellite imagery from 1954 to 2003 (A and B) and a very schematic geomorphological map (C) in which the main anthropic features are reported. D) the high resolution satellite imagery of Stelvio Pass captured in 2023.

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Historical volcanism geosites of La Palma (Canary Islands). Geoconservation and natural and anthropic threats

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Volcanism is one of the main geological processes that significantly impact humans, both by providing fertile soils and suitable landscapes, but also posing a variety of geohazards. Historical volcanism illustrates the behaviour of volcanoes in the recent past and its study is crucial to improve the assessment of the geohazard and volcanic risk of future eruptions. Thus, understanding recent volcanism can help human resilience in volcanic risk areas, such as the Canary Islands (Spain).

Volcanic archipelagos are ranked by the IPCC (Intergovernmental Panel on Climate Change) as one of the most vulnerable places on Earth, the main threat being the rising of global sea level. Furthermore, historical volcanic geosites are the most susceptible geoheritage to the impacts of sea level rise in Canary Islands because of their lava deltas, which are formed on the coast. While this is one of the main issues for the Canary Islands geoheritage, the risk of degradation is not only determined by natural threats. Human occupation and land use pressure is very high in the Canary archipelago: i) it is the most visited tourist destinations in Spain (15.2 million foreign visitors to the Canary Islands in 2024), ii) a strong agricultural use of the territory, and iii) a high population density concentrated on the coast.

La Palma Island is the most active of the archipelago, hosting half of the historical eruptions [1]. Eight of them are hybrid strombolian edifices, aligned along the Cumbre Vieja Ridge, and seven of them formed deltas when the lava flows reached the sea (fig. 1). These seven eruptions are included in the Spanish National Geoheritage Inventory (IELIG, acronym), because of their high scientific value [2,3].

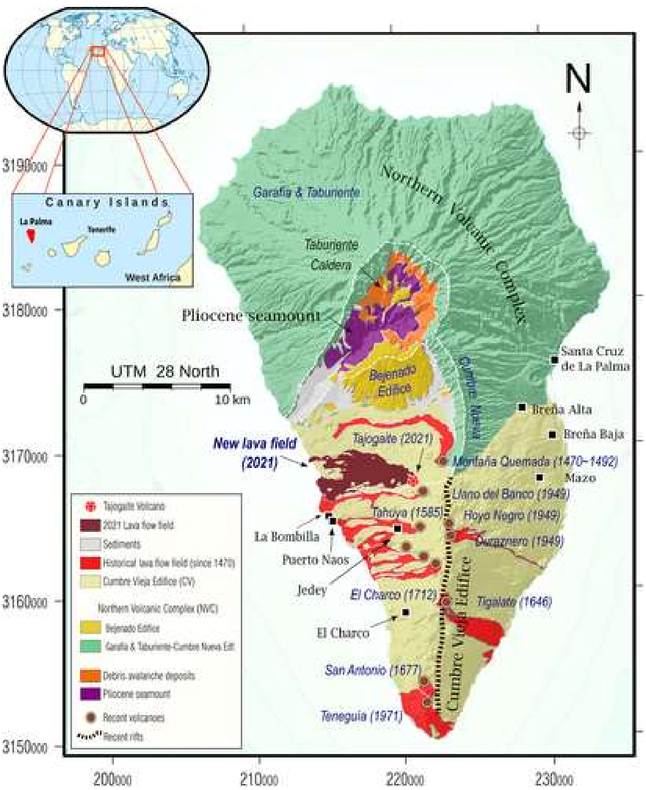

Figure 1. Simplified geological map of La Palma Island, with the historical eruptions drawn in red, with their names and dates [4].

The cinder cones are located inside ‘Cumbre Vieja Natural Park’, and the ‘Teneguía Volcanoes Natural Monument’, and thus, are well protected. Nevertheless, most of their lava fields and lava deltas´ surface is

unprotected. This has led to the most vulnerable elements of the historical volcanic geosites being heavily anthropized, and this precedent is set to affect the newly formed Tajogaite Volcano (2021 eruption), with its lava deltas and a significant portion of lava field already damaged only three years after the eruption ended.
The state of conservation of the La Palma´s historical volcanoes decreases northwards where the density of population is the highest (Los Llanos de Aridane and El Paso municipalities). Teneguía and San Antonio volcanoes are the best preserved due to their legal protection, and Tahuya and San Juan volcanoes are the most damaged. Tigalate is also well preserved, due to its location in the steepest area of Cumbre Vieja and to its lava deltas being isolated. El Charco Volcano shows the largest mismatch in conservation, having its cinder cone and lava field well preserved (also due to a steep topography), but the lava delta is completely modified by human activity. El Charco´s lava delta is part of an 8 km wide lava platform formed by coalescence with Tahuya, San Juan, and now Tajogaite´s lava deltas, and this geography has enabled a development of villages and crop fields.
These facts highlight the importance of legally protecting historic volcanic geosites for the effective conservation of geological heritage. In the long-term, it is implied that protecting only volcanic cones diminishes the tourism and educational value in the inventory valuations, thus endangering scientific research and dissemination.
From a societal perspective, other determining factors come into play. The lava deltas are the areas traditionally occupied for agricultural development, especially bananas since the mid-20th century. These areas are also in great demand by the residential use and hotels. On one hand, the inability to properly study the historical volcanism in the most anthropized volcanic elements, makes the scientific research and the volcanic risk assessments difficult. This is especially concerning in La Palma, as a higher population is concentrated on the flanks of Cumbre Vieja active Volcanic Ridge, so exposure is very high, as seen during the 2021 eruption [5]. On the other hand, degradation of lava deltas not only does affect the geosite value, but also properties and infrastructure. There are many examples of villages built on historical lava deltas (La Bombilla, Puerto Naos, Las Indias, and El Remo), that are exposed to the impact of sea level rise in the coming decades and the impact of potential eruptions in the next century. Therefore, geoconservation of La Palma´s lava deltas are a matter of science, nature conservation, and socioeconomic interest.

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Geoheritage degradation risk: a systematic literature review

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The assessment of degradation risks associated with geoheritage is a relatively unexplored topic, despite its critical importance for effective management and conservation. Geoheritage can severely face significant threats from both natural factors and human-induced impacts. In many countries, the lack of systematic inventories, inadequate management, and the consequences of climate change have endangered geosites, leading to their potential deterioration or complete loss [1]. Consequently, developing assessment procedures to evaluate degradation risks and monitor conservation status is a priority for researchers. Current set of methods for identifying and mitigating geoheritage degradation risks often lack standardized frameworks, approaches, and terminology. This paper seeks to lay the groundwork for assessing geosite degradation risks by outlining shared investigation schemes, identifying current research gaps, and highlighting potential areas for improvement. We analyzed the evolution of geoconservation studies over the past 20 years, particularly focusing on geoheritage degradation risks, and conducted the first systematic literature review on degradation risk and its related concepts. This investigation involved an extensive search of major literature databases, which yielded 295 relevant records, subsequently narrowed down to 130 through a screening process. This study provided an in-depth understanding of the various methodologies and frameworks used to assess the risk of geoheritage degradation. This analysis was crucial for exploring both established and novel methodologies, offering a comprehensive overview of current practices and highlighting potential advancements in the field [3].

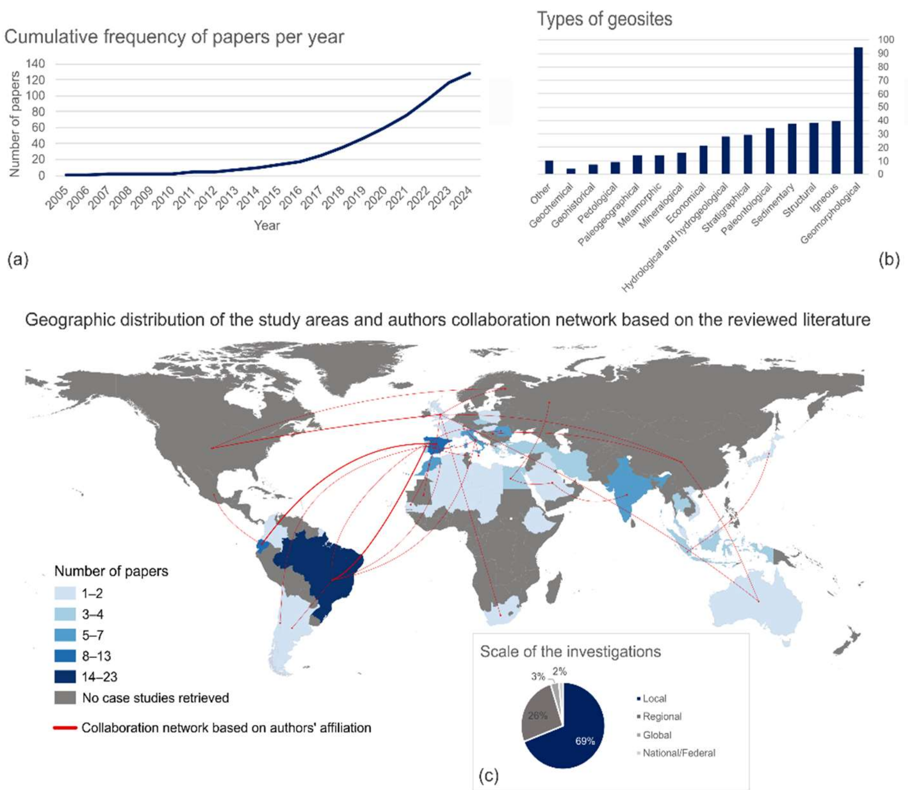

Figure 1. Geographic framework of the selected literature (study areas and collaboration network among authors). The plots in the frames illustrate: the cumulative curve of the number of papers published per year (a), the number of papers for each type of geoheritage considered (b), and the spatial scale of the studies in the reviewed literature (c). Figure taken from [3].

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Methodological proposal for the quantitative assessment of the degradation risk of geosites

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In recent years, many geoconservation studies have focused on the degradation risk of geosites. The identification of threats to geoheritage, whether natural or anthropogenic in origin, and the consequent assessment of degradation risk, is of paramount importance to define any geoconservation strategy. Several methodologies, both qualitative and quantitative, have been proposed to assess the degradation risk of geosites [1]. Most of them revolve around the concepts of "fragility", "vulnerability", "sensitivity" etc., terms that have been used inconsistently over the years [2]. In many cases, these assessments are incorporated into the procedures for assessing the geosite value (e.g. [3]).
Starting from an evaluation of the strengths and weaknesses of existing methodologies, we propose a new quantitative methodology for the assessment of the degradation risk of geosites. Three aspects of degradation risk are assessed: i) fragility, which depends on the intrinsic characteristics of the geosite; ii) natural vulnerability, depending on extrinsic natural factors, i.e., active natural processes; iii) anthropogenic vulnerability, depending on extrinsic anthropogenic factors, i.e., human action. The methodology also takes into account the assessment of protection measures, if any, which can be considered measures to mitigate the vulnerability of geosites. Each of these four parameters was assessed by means of a set of indicators, to which numerical scores were attributed.
The methodology was tested on two different inventories of geosites, the first concerning the Liguria region (Northwestern Italy), the second in the Hérens Valley of the Pennine Alps (Valais, Switzerland). The methodology is structured to be easily replicable in other study areas and in different geographical-geomorphological contexts, and the results may constitute an important tool for outlining effective management strategies of geosites.

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Geoclimbing at La Pedriza del Manzanares (Madrid, Spain). Natural and anthropogenic weathering processes

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Introduction

La Pedriza del Manzanares (Madrid, Spain) is one of the most important granitic landscapes in Europe.

Its geomorphological worth poses a global reference to the study of granite reliefs. Additionally, it functions as a natural laboratory for examining physical and chemical weathering processes. This geomorphological weald entails a high value from a scenic and sporting point of view, particularly for climbing [1]. La Pedriza del Manzanares is the main climbing school in the Madrid region. It is listed as a Site of Geological Interest (LIG) in nearly all existing inventories and was declared a Natural Site of National Interest in 1930. In 1978 it became part of the Cuenca Alta del Manzanares Natural Park, reclassified as a Regional Park in 1985. In the 1990s it became a UNESCO Biosphere Reserve. In 2013, the creation of the Sierra de Guadarrama National Park, which included La Pedriza del Manzanares, was approved.

This article is within the framework of the UNESCO International Project IGCP 714 - 3GEO: Geo-Geoclimbing & Geotrekking in Geoparks, which aims to promote the dissemination of geosciences [2,3]. Climbing in natural environments is a sporting activity of great interest for understanding the forms and processes that shape rocks. The weathering processes observed on rock slabs vary based on their orientation, allowing us to identify distinct patterns and characteristics.

Natural disturbance processes

Rock surfaces show a wide variety of textures and shapes related to surface alteration processes, sometimes initiated under burial conditions. Their texture and morphology depend on intrinsic and external factors. Intrinsic factors are: mineralogy, mineral size, the presence of open and closed fissures, dykes and their mineralogy, flow and orientation structures formed during the magma cooling process, laxities parallel to the wall surface, etc. External factors generally relate to the climatic and environmental conditions to which the rocks are exposed. Other factors related to environmental conditions and which also affect the morphology of the outcrops are: the presence of lichens and mosses, and the existence of patinas with calcifications and other chemical precipitates.

The primary weathering processes affecting granitic rocks are hydrolysis (which transforms potassium feldspars into kaolinite), oxidation (which significantly impacts biotites), crystallization of salts (which contributes to the separation of mineral grains), and temperature fluctuations. Furthermore, the presence of lichens and mosses plays a role in the processes of alteration and/or stabilization of the rock.

The geomorphological features of the walls that influence climbing (Figure 1) vary greatly in shape and size [1,4]. Minor shapes range from a few millimetres to several centimetres. The most common features include micro-roughness, micro-sheets, hardened surfaces, micro-dikes, and xenoliths. Larger forms encompass morphologies typical of granitic modeling, such as tafoni, piles, dykes, fractures, and grooves.

Figure 1. Examples of some of the natural influences on climbing, a) tafoni, b) microflats, c) xenolith (Gabarro).

In areas such as La Pedriza, where the rock slabs are relatively smooth, the forms of surface alteration are significantly influenced by their orientation, whether north or south [1,4]. In heterogeneous rocks like granite, temperature fluctuations lead to differential expansion and contraction of each mineral grain, promoting surface disaggregation. The effectiveness of these temperature changes is contingent upon both the temperature itself and the orientation of the rocks. Furthermore, temperature variations control the heating and cooling of the surface and also regulate the cycles of freezing and thawing of interstitial water between the mineral grains of the altered rocks, thereby facilitating the separation of the minerals from one another.

Rock heating is influenced by two mechanisms: direct insolation and convective processes. When rock heating occurs due to insolation, i.e., the direct effect of solar radiation, temperature gradients are high and fluctuate over short periods, resulting in cycles where the rock heats up and cools down rapidly. Direct insolation on south-facing walls, even on clear winter days, can raise their temperatures to exceed 40°C in winter and reach 60°C in summer [4]. Convective processes are regulated by ambient air temperature. In the absence of direct solar radiation, these processes work to homogenize the temperature across the entire wall. They are effective at night, on cloudy days, and on shaded walls, typically responsible for the periods when minimum and average temperatures are recorded. Additionally, convective processes control the temperatures of north-facing walls during the summer, gradually increasing the wall temperature from early morning hours. For instance, in December, temperatures on south-facing walls can range from 0°C to approximately 45°C, with humidity levels between 20% and 90%. In contrast, north-facing walls during the same time period typically experience temperatures ranging from 0°C to 10°C, with humidity levels between 40% and 98%.

According to the provided information, alteration patterns can be identified based on whether walls face north or south. On north-facing walls (Figure 2a), the weathering of the rock primarily occurs through chemical processes such as hydrolysis and oxidation. These walls tend to be smoother and exhibit fewer irregularities. Additionally, north-facing walls are often covered with lichen, which contributes to the stabilization of the rock surface. In contrast, south-facing walls (Figure 2b) display irregularities and micro-reliefs that result from mineral disaggregation and loosening, caused by significant daily thermal fluctuations in the rock. The flaking observed on south-facing walls promotes the detachment of the uppermost layer, which can range in thickness from several millimetres to a few centimetres.

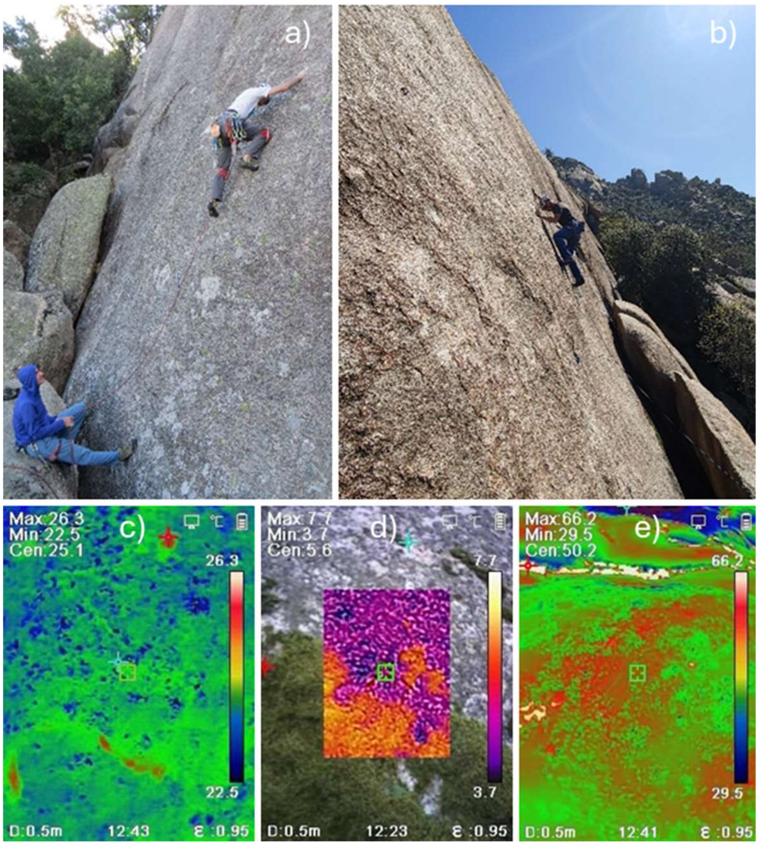

Figure 2. a) Friction climbing on a north-facing wall. Smooth surface covered with lichen, b) friction climbing on a south-facing wall. Microrugosities and microgrooves abound, c) thermal image of a north-facing wall in July, d) thermal image of a north-facing wall in December (the biological activity of lichens and mosses contributes to tempering the rock temperature), e) Thermal image of a south-facing wall in July.

Anthropogenic processes and forms

The mountaineering tradition in the region dates back to the same period as the naturalist explorations, with Casiano de Prado being the first to climb the peak of El Yelmo before 1866. Much of what we know about climbing in La Pedriza prior to 1920 can be attributed to Bernaldo de Quirós, who wrote the first version of "La Pedriza del Real de Manzanares," published in the "Anuario del Club Alpino Español" as early as 1921. From the second decade of the 20th century onwards, mountaineering activity in Guadarrama began to flourish. Initially, mountaineering groups not only pursued adventure but also held a genuine scientific and cultural curiosity, which allowed them to enhance their understanding of the mountain and contribute to its conservation and protection.

From the 1950s onwards, the number of climbers and the opening of new routes increased exponentially. The desire to reach summits and establish routes on these smooth walls sparked the imagination of climbers, who developed somewhat aggressive techniques that enabled them to ascend. At that time, climbing was done with hard boots, which made it difficult to pass through these smooth surfaces. To progress, climbers of that era carved ‘maceados’, or small steps on the rock, to place the toe of their boots and continue their ascent. It was also common to use ‘burins’, where a hole was made one or two centimetres deep, and a screw was hammered in. Over time, when the screws came out, the hole remained on the slab.

From the 1980s onwards and in recent times, friction climbing has evolved towards a sportier and cleaner approach. However, these new times are not without their impacts. The opening of new routes in free climbing has led to the cleaning and brushing of walls, which involves removing moss and lichen from various areas. Additionally, the significant increase in the number of climbers over the past two decades has resulted in many routes being repeated hundreds of times, which causes the walls to become polished due to friction with climbing shoes.

The ‘Cerdito’ (piglet) is one of the most emblematic boulders in La Pedriza. This rock, which resembles its name, is located in the meadow at the foot of Peña Sirio, on the left bank of the Arroyo de las Majadillas. In our country, the ‘Cerdito’ is not only a symbol but also holds significant patrimonial value; thousands of hikers and climbers have ascended it. During the 1950s and 1960s, it served as a location for practicing how to place 'burins' and perform 'maceados.' Its appearance is characterized by tafoni and inverted slopes, and it has two large piles at the top. Finally, it has witnessed thousands of mountaineers bivouacking in its surroundings for at least the last hundred years. Doesn't it deserve a heritage designation?

Figure 3. The Cerdito and 3D models. a) Natural forms in the Cerdito; tafoni, inverted slopes and piles (south orientation), b) anthropic forms, "maceados" and burins (east orientation), c) 3D model of a climbing block with alteration of the rock due to the use of a lot of magnesium (white spots), d) 3D model of a climbing wall affected by a forest fire [5].

The excessive use of magnesium is another impact on the rock, visually affecting the walls and distorting the natural landscape (Figure 3c). The primary effect of magnesium is on the bouldering environment, which involves climbing small granite blocks without the use of ropes.

Another significant anthropogenic impact on climbing areas, also related to temperature, is forest fires [5]. These fires cause mechanical rock breakage and thermochemical reactions (Figure 3d). The resulting changes lead to a major transformation of rock outcrops and accelerate weathering processes induced by fire. The mechanical effects of fire can occur in just a few minutes and are comparable to those caused by temperature fluctuations under natural conditions over thousands of years. Fire causes spalling, cracking, granular disaggregation, and thermochemical weathering.

Conclusion

The shaping of rocks in natural areas that are frequently visited by many people is influenced by both natural and anthropogenic processes. The combination of these processes results in a diverse array of textures and morphologies on the granite walls, the interpretation of which can be subjective. Therefore, it is crucial to have a solid understanding of geology in order to distinguish between shapes created by natural weathering processes and those that are man-made, such as carvings, steps, piles, petroglyphs, etc.). In this regard, the IGCP 714 project is undertaking significant educational efforts [3, 4]. By using 3D models, it aims to bring aspects of nature into the classroom. These models cover a range of scales, from observing minerals in hand specimens to large slabs where climbing is practiced.

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Impact of climbing in soil compaction and erosion of La Pedriza Geosite

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La Pedriza del Manzanares (approximately 3,200 ha, at the NW of the Autonomous Community of Madrid) is an outstanding geological site characterised by a remarkable and diverse granite landscape [1], one of the most important in the Iberian Peninsula and Europe. It includes several geosites of the Spanish Inventory of Geological Sites (https://info.igme.es/ielig/). La Pedriza is also one of the major climbing destinations in Spain, with more than a century of mountaineer tradition, and a hotspot of world climbing in slabs (grip climbing) [2]. With its over >3,000 sport climbing routes and >2,500 boulders, the quality of its rock, and the population size of Madrid (>7 million residents), La Pedriza attracts thousands of climbers annually. Consequently, it is of paramount importance to consider the impact that such outdoor activity may cause on the natural environment. La Pedriza is under the umbrella of multiple environmental protection figures (Upper Manzanares Basin Regional Park, UNESCO Biosphere Reserve, and Red Natura 200) and it is included within the Guadarrama National Park. La Pedriza is zoned in 9 categories according to the value and fragility of its resources and its capacity to accommodate different uses, in order to minimise negative impacts and ensure a use compatible with the conservation of protected values. La Pedriza corresponds to the third most restrictive of these categories, which is an area of restricted use due to its high degree of naturalness. This means that certain activities are regulated depending on the impact they produce.

Figure 1. Climbers in "Quebrantaherraduras inf." crag, near to the infiltration ring at the base of the wall.

The high visitation for climbing raises concerns regarding geological heritage preservation, as climbing can contribute to rock erosion, lichen loss, and soil degradation. To mitigate these impacts, access regulations are in place, including seasonal restrictions in sensitive areas to protect nesting raptors and limit excessive wear on rock surfaces. These regulations classify areas into different categories: A (permanently closed to climbing), B1 (temporary restrictions on specific routes), B2 (temporary closure of entire sectors), and B3 (restricted access affecting approach routes). Climbers must consult updated regulations, as restrictions may change annually based on conservation needs. Recent studies highlight the need for sustainable climbing practices, balancing recreational use with conservation efforts. Implementing educational programs, route maintenance protocols, and visitor caps in vulnerable zones are among the proposed measures to minimize damage, while maintaining The Pedriza's status as a premier climbing site. To analyse the impact produced by climbing and to guide the management of the geological heritage of the National Park, several studies are being carried out to identify and quantify the effects produced by this sport: 1) analysis of potential damage (pressures) in climbing crags, 2) degree of compaction and loss of infiltration in soils at the base ground of climbing walls and, 3) impact of soil erosion due to trampling from exposed roots on climbing walls.

Pressures: Potential damage on climbing walls

The analysis of potential damage of climbing in protected areas has been developed following a "Categorization Method" that involves the construction of a categorization matrix based on four key variables: accessibility, number of routes, route difficulty, and crag developed age. Each variable is quantified through standardized data collection and categorization procedures to ensure consistency in the final matrix. Accessibility (distance and elevation gain) was measured using Google Earth PRO and Outdooractive AG like two complementary tools, with the path creation tool in Google Earth PRO when the trail was visible in satellite imagery and with Outdooractive AG when not. The most used approach routes, as documented in [3], were selected as reference paths. These parameters were then categorized into a scoring system, where lower values indicated greater accessibility, assigning a final matrix value inversely proportional to the sum of the distance and elevation scores. Number of routes was obtained by cross-referencing data from climbing guidebooks [3] and the online climbing database theCrag.com. Since theCrag.com often lists additional routes not included in the guidebook, the higher route count was taken for categorization. A three-tier classification system was applied to assign each sector a final matrix value. Route difficulty was analysed using data from the same sources, simplifying the French grading system into three categories (low, medium, and high difficulty) based on the most frequently climbed grade identified by [4]. The percentage of routes per difficulty category was weighted (1 for low, 2 for medium, and 3 for high) to calculate a composite difficulty score per sector. Lower difficulty scores were assigned higher matrix values, reflecting the hypothesis that less difficult sectors tend to have higher climbing compactness. Crag development age was determined using historical records from different climbing guidebooks and additional local climbers' personal communications. The crag's opening date was defined as the first recorded route, regardless of subsequent development. Crags were categorized into three age groups, with older sectors receiving higher matrix values to account for their potential climbing significance. Finally, the matrix values assigned to each variable were summed to compute the potentiality score for each sector. This methodological framework allows for an objective and systematic assessment of climbing sectors, facilitating comparative analysis and strategic decision-making in climbing area management.

SECTOR	MATRIX VALUE				POTENTIALITY	
	ACCESSIBILITY	Nº OF ROUTES	ROUTE DIFFICULTY	DEVELOPED AGE		
Gusarapo	3	2	3	2	10	Hight
Quebrantaherraduras Inf.	2	2	3	2	9	Hight
Placas de M. Á. Blanco	3	3	2	1	9	Hight
Cancho Islazo	2	2	2	2	8	Medium
Muro Víbora	2	1	3	1	7	Medium
La Peseta	1	2	1	3	7	Medium
El Pájaro*	1	1	1	3	6*	Low*

Figure 2. Results of potential damage in climbing sectors of La Pedriza using the categorization method.

Results (Fig 2) indicate that climbing crags with better accessibility, higher number of climbing routes and lower difficulty are those that in general have higher values for the impact potential of the activity, while less accessible, with fewer or more difficult (and more recent) routes, are those with lower values for the impact potential. However, there are some influencing factors that have not been taken into account in the matrix. *Older areas, such as "El Pájaro", which are very popular and have been open for many decades, have a low value, possibly limited by 1) the accessibility and low number of easy routes and 2) the classic/traditional climbing style, which requires special skills and limits the influx of the public.

Analysis of soil compaction and loss of infiltration

We estimate soil compaction by means of infiltration tests, at least three measures were done per area using the single ring method, we measure the infiltration time until the stabilization of the measurement. We have considered as impermeable (high compaction) all measurements exceeding 1h for the first time measurement. We note that the process of soil compaction is evident in all climbing sectors. The analyses carried out at the base of the climbing wall clearly show the effect (Fig. 3), as most of the results show that the soil is completely impermeable to infiltration. To rule out other factors, in those crags that have walls without routes, compaction has been analysed, and they show high infiltration values, i.e. there is no compaction due to trampling (i.e.: “Quebrantaherraduras inf.”). As soon as we move away from the climbing area, the values recover, and the soil shows higher infiltration values. Contrary to what the potentiality matrix indicates, although the crag is of recent opening, the impacts on the base of the climbing wall are very rapid, as shown for example by “Víbora” or “Cancho Islazo” (Fig 3d). Therefore, it does not take many years to generate the transformation in soil properties. The most crowded and easy-access site is “Gusarapo” (Fig 3c), with several high impacted test, even out of the base of the climbing wall.

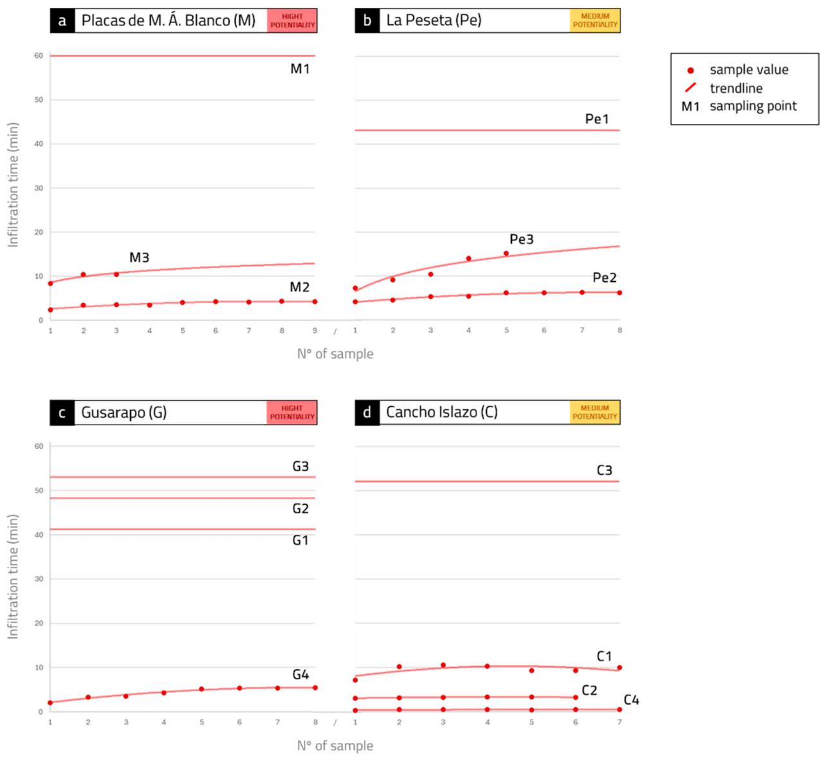

Figure 3. Infiltration time of samples along different climbing crags: a) “Placas de Miguel Angel Blanco”, an easy access climbing wall, with infiltration test in the base ground of the wall (M1) and out of climbing influence (M2 and M3), b) the hard grade wall of “La Peseta”, with Pe1 (base) and surroundings (Pe2 and Pe3), c) the often crowded “Gusarapo” crag, with most of the samples with high degree of compaction, and d) the less visited young sector of “Cancho Islazo”, with visible effects of compactions despite its low potential impact. *Horizontal trend lines are considered impermeable after 1h (only one measurement).

Analyses of soil erosion in climbing spots and access trails

To quantify soil erosion retrospectively, we rely on standard dendrogeomorphological approaches [5]. This method is based on the dating of the first exposure year in the tree ring records of the analyzed roots and determines the soil eroded using Lidar topography (Fig. 4). This approach has been applied at 153 exposed roots in 7 selected climbing spot areas characterized by different number of routes, difficulty and approaching time. Because climbing spots are usually inaccessible, we assume that trails were created since the equipment of routes. Thus, the year of route installations provided in local climbing guides allows for validation. Our result suggests changes in the soil erosion magnitude across the spot climbing sites. Overall, higher soil erosion rates over the last two decades have been identified (> 3 mm/yr) (Fig. 5). Soil erosion shows a bimodal behaviour, which could be related to soil fragility thresholds. In fact, our results suggest a high fragility to soil erosion, because older climbing spot areas show comparable erosion rates than new spot areas. This suggests that once new spot areas are equipped, soil erosion could evolve quickly and become not reversible if immediate measures are not put in places.

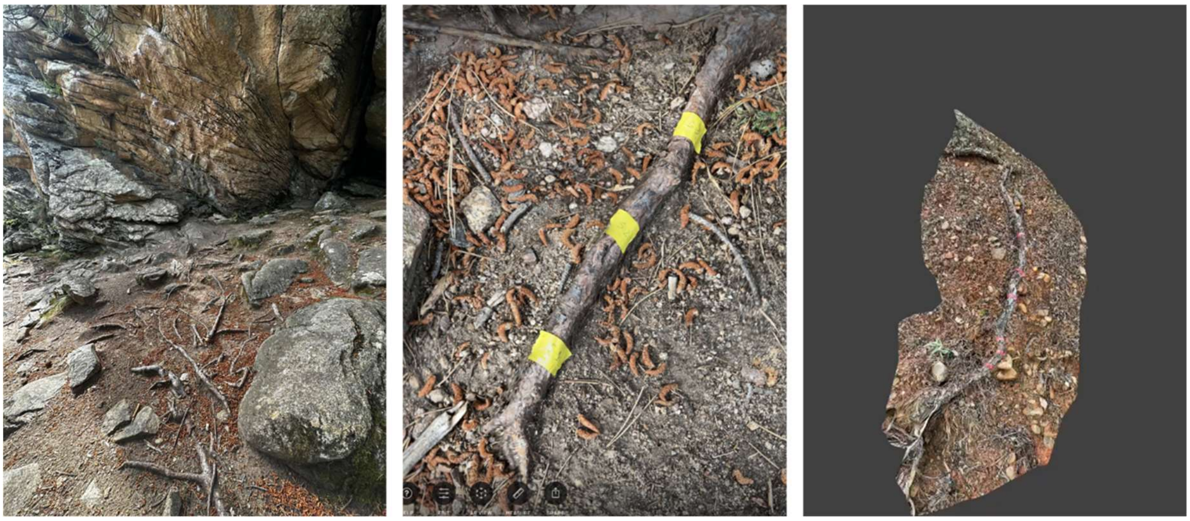

Figure 4. Different views of exposed roots at climbing spots. The right images correspond with Lidar model obtained from terrestrial Lidar.

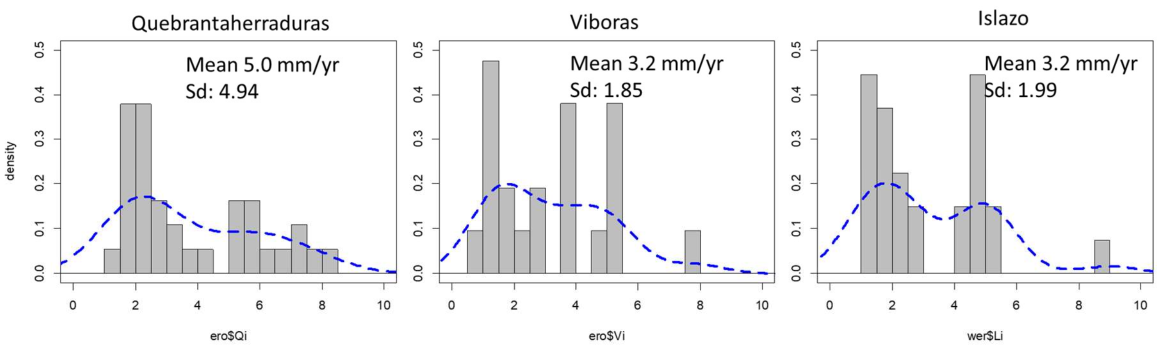

Figure 5. Density distribution of mean annual erosion rates at three selected sites, “Quebrataherraduras”, “Vibora” and “Cancho Islazo”.

Conclusions

The study integrates the analysis of potential damage from climbing activities with soil compaction and erosion data, offering a comprehensive understanding of pressures in La Pedriza Geosite. The categorization of climbing sectors suggests that more accessible areas with easier routes generally show higher potential for environmental impact. This correlates with the observed rapid soil compaction, especially at the bases of climbing walls, where infiltration becomes nearly impossible due to trampling. Interestingly, even newly developed sectors, like “Víbora” and “Cancho Islazo”, exhibit significant soil compaction within just a few years of the start of developing, despite their lower potential impact scores. This contrasts with older sectors, such as the “El Pájaro”, which show low impact despite their popularity, likely due to their limited accessibility and traditional climbing styles. Soil erosion analysis further supports these findings, revealing significant erosion rates in both new and old climbing areas, suggesting that once soil degradation begins, it escalates quickly. The erosion pattern aligns with areas that experience higher climber traffic and accessibility, indicating that the impacts of climbing on soil can rapidly become irreversible if not managed properly. This comparison highlights that climbing areas with higher potential impact scores also exhibit faster soil compaction and erosion, reinforcing the need for adequate conservation measures to mitigate the long-term degradation of a unique geosite.

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Criteria and indicators of urban geoheritage assessment for geoturistic use: the cultural values importance of geoheritage in Rome (Italy)

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Over the past 30 years, scientific research on geodiversity has yielded numerous studies concerning the inventory, assessment, protection, and management of sites and elements representative of abiotic nature across diverse landscapes [1]. Within this context, geocultural heritage and urban geoheritage encompass geodiversity sites where geological features interact with cultural elements.

Analyzing geodiversity in urban environments presents the challenge of identifying geological and geomorphological features within landscapes heavily modified by intense anthropogenic morphogenesis. Urban geosites represent a blend of natural and cultural aspects [2]. Even when other values predominate, the geo-scientific value remains significant as evidence to the local Earth's history, particularly within the Anthropocene. This raises the questions: Is the geo-scientific value sufficient to support the selection of urban geosites for geotourism? How significant is the cultural value of urban geosites? What distinguishes urban geoheritage from geocultural heritage?

Multidisciplinary geohistorical analysis facilitates the identification of urban geosites [3]. This paper proposes a quantitative urban geoheritage assessment method tailored for geotourism and reflects on the importance of cultural values in urban geosites assessment. A review of the incorporation of cultural values in geoheritage assessment literature supports our conclusions: densely populated and urbanized cities, characterized by centuries of layered urban transformations yet retaining geological and geomorphological features, necessitate geoheritage assessment methods that emphasize cultural aspects. Consequently, for urban geoheritage, the cultural value not only interacts with the geo-scientific value but also enhances its perceived significance.

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Impacts of climate change on the coastal geoheritage of Timanfaya National Park, Lanzarote Island, Spain

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Studies on the impact of climate change on natural heritage are extensive, especially on the biotic component. However, there is still scarce research on the effects on geological heritage [1,2]. The research proposed here is designed to assess vulnerability to global change of the geological heritage representative for the Timanfaya National Park (Lanzarote Island, Spain) and to describe impacts and natural systems and their repercussions for public use. One of the effects of climate change identified on the Timanfaya coastline is the global rise in sea level due to the melting of the ice caps. This fact, together with the increased incidence of extreme meteorological phenomena, makes the coast of this National Park one of the scenarios chosen for this study. In the coastal sector, there are two Geosites of the official Spanish inventory: i) 'IC1047 (which is also part of the Geosite VC007 of international relevance): Coastal and littoral morphologies of the lava flows of the historical eruption of Timanfaya (1730-36)', and ii) 'IC1012: Coastal boulder deposit of the Laja del Cochino'. [3]

Detailed geomorphological mapping is being carried out using drones, and fieldwork with rock hardness measurements to characterize the sectors already affected by the erosive processes that are increasing cliff retreat and have affected the coastal path of the National Park. This path is the only one available to visitors on foot. The model and data obtained is being used to map the coastal sector that will be affected by the rise in sea level predicted in the scenarios proposed by the IPCC (Intergovernmental Panel on Climate Change) over the next 100 years.

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SESSION 5: CONCEPTUAL ISSUES FOR GEOCONSERVATION AND GEOTOURISM

Convener: Manu Monge-Ganuzas

Conceptual framework for geoconservation: geodiversity is a parameter and geoconservation must focus on geological heritage

Díaz-Martínez E., Carcavilla L., Vegas J.

Guiding Principles for management of Geosites/Geoparks, leading to Geo-education and Geotourism

Semeniuk V., Brocx M.

Conceptual framework for geoconservation: geodiversity is a parameter and geoconservation must focus on geological heritage

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During the last decade we have seen a progressive increase of conceptual errors in the use of basic terminology and with regard to the general conceptual framework for geoconservation. This often leads to the erroneous assignment of typological classifications or management competencies to administrative bodies and professional groups that lack the academic preparation and scientific experience expected for proper sustainable management of geological heritage, including the inventory, analysis and assessment of geological elements, the development of conservation and public use strategies and plans, etc. The resulting situation seriously affects sites and collections that, as is often the case with geological heritage, are not renewable (and certainly not resilient) and may be lost forever. For this reason, it is appropriate to be strict and explain in greater detail the argument that leads to something that should be obvious: that geological elements are part of nature and, if they have sufficient value, they are considered geoheritage, which is a type of natural heritage [1,2].

The concept of geological element refers to the abiotic components of nature (rocks, minerals, sediments, water), with their shape and structure resulting from natural processes. If physical and chemical processes predominate, we know them as geological processes (as opposed to biological processes), and the sciences that study the geological elements and processes are known as geosciences. For most readers this should be obvious, but it is not for some who learned geomorphology from geography, since the paradigm in their case is that landforms are not geological elements and therefore that geomorphology is not an area of specialization within geology. This occurs amongst some geographers and their sphere of influence in different countries, and continues to generate conflict regarding the inclusive use of the prefix geo-. That is why we consider the expression “geology and geomorphology” redundant, or disagree with the reluctance to consider landforms as geological elements. In this sense, the paradigm we use is the inclusive one, as stated by UNESCO in its classification of scientific areas into disciplines (Geology is 2506) and subdisciplines (Geomorphology is 2506.07). In Spain, this norm was adopted in 1983, following the CSIC Resolution of 23 September, which was published in the State’s National Bulletin (BOE) of 14 October 1983.
Generally speaking, geological heritage consists of geological elements with value attributed or assigned due to their potential use. This value is a subjective aspect of heritage, subject to the opinion, preferences and priorities of society. At the same time, value is an essential parameter of geological heritage, since what has no value is not considered geological heritage. Value is a parameter determined for geological sites and collections, and it must be established by the corresponding specialist depending on the discipline: a petrologist in the case of rocks, a geomorphologist in the case of landforms, a palaeontologist in the case of fossils, etc. Geological heritage always consists of an objective part (the geological elements) and a subjective part (their value).

The management of geoheritage requires conservation criteria and methodologies that depend on the type of geological elements, so that (a) movable geoheritage (collections) is distinguished from immovable geoheritage (sites), and (b) cultural heritage (related to intentional human activity) is distinguished from natural heritage (resulting from natural processes). If done properly, it is possible to identify different types of heritage with overlapping interests, such as cultural heritage with geological interest: a 19th century geological map, a 16th century painting depicting a rock fall, or a ceramic plaque indicating the level reached by flood waters. The type of geological heritage is not determined by the type of value. Value only determines whether or not a geological element is considered geological heritage. For example, according to their natural origin, fossils are natural elements, not cultural. Hence, if a fossil is identified to have a high scientific value, that would imply it is palaeontological heritage, which is a type of geological heritage, and thus a type of natural heritage.

Geological heritage always has scientific value, whether it is greater or lesser, or whether or not the geological element also has other types of value (educational or touristic). The study of geological heritage is a scientific discipline of geology precisely because it deals with geological elements with scientific value. A rock that has no scientific value, but is admired or venerated because it has a particular shape, or because it was assigned a mystical or religious value, does not necessarily need to be considered geological heritage. Instead, that rock may be considered a geological element with cultural value. Mistaking the type of geological element with the type of value is a common error. Instead, the type of geological element is what determines the type of heritage. Geological heritage always consists of geological elements, so there cannot ever exist immaterial geological heritage. Similarly, a historical building made of stone cannot be geological heritage. Neither is the house where a renowned geologist lived, or the field notebook that she/he used.

The term geodiversity refers to the variety of geological elements. Therefore, geodiversity must be considered as a parameter that refers to the diversity of geological elements, including rocks, minerals, fossils, soils, landforms, geological formations and units, and landscapes present in a territory [1]. The term geodiversity is meaningless if it does not refer to a certain territory. Using the term geodiversity to refer to all the geological elements of the planet in a generic way, or without reference to a territory, implies a different meaning from its original etymology. Besides, there is already a term for that purpose: gea. Sadly, most of the times that the term geodiversity is used in the literature, it may be replaced by the word gea, which would be more correct and appropriate. Geodiversity is the parameter that measures the variety of the geological elements in a territory, and this measurement should be done with statistical indices, as is also the case with biodiversity. The term geodiversity should not be used to refer to geological elements nor to geological heritage. Geological heritage refers to geological elements with scientific value which we want to conserve in order to leverage their potential use. Geodiversity and geoheritage refer to different things and are thus not interchangeable nor correlatable: high relevance geological heritage may have very low geodiversity, and there may be places with very high geodiversity that are not necessarily considered geological heritage.

Geological elements record the origin and evolution of Earth (including climate and life on it), and so they always have scientific value. The information provided by geological heritage is frequently valuable for science, including both movable objects (fossils, minerals, etc.) and their host site, where there may be other evidence of interest. In addition to the scientific value, geological heritage often also has educational value due to its potential use for teaching, tourist value due to its beauty and/or spectacularity, and even spiritual value due to its sacred character.

The term geoconservation refers to the set of techniques and measures (strategies, programs and actions) taken to ensure the conservation of geological heritage [1]. Amongst the techniques and measures used in geoconservation we have inventories, physical and legal protection, management and public use plans, and public outreach (dissemination). The main objective of geoconservation is that society and future generations may leverage the potential use of geological heritage. The successive recent scientific and technological advances show us that, with time and the emergence of new technologies, more and more information can be obtained from a sample, and this can be done with less and less impact on the sample (i.e., with less destructive techniques). Consequently, it is essential to manage geological heritage properly, in order to have properly preserved samples that can later be used for study.

All too frequently, newcomers to the field of geoconservation use the term geodiversity in a similar way to what happened with the term biodiversity when it started to be used in the 1980s: instead of using it to refer to the parameter that measures the diversity, it is used to refer to the elements used in the calculation. It is evident that the conservation of geological heritage requires establishing priorities and selecting specific objectives, since it is impossible to conserve everything. In turn, expressions such as geodiversity site or geodiversity element, proposed to refer to geological heritage, are highly misleading terms. The calculation of geodiversity considers all geological elements, including those with little or no value.

An analysis of the evolution of the conceptual framework for geoconservation on a global scale over the more than three decades since the scientific community began to address this issue, shows that this conceptual framework has been gradually misunderstood and used incorrectly. The methodological and practical advances in geoconservation depend on a proper use of the terminology.

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Guiding Principles for management of Geosites/Geoparks, leading to Geo-education and Geotourism

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Geoheritage, geo-education and geotourism has led to better defining the terms associated with these endeavours and understanding management of areas of geoheritage significance. The key aspects deriving from the study, protection, management, and education in Geology can be summarised as the "8Gs", *i.e.*, Geology itself, Geodiversity, Geoheritage, Geoconservation, Geosites/Geoparks, Geo-management, Geo-education, and Geotourism [1] (Fig. 1).

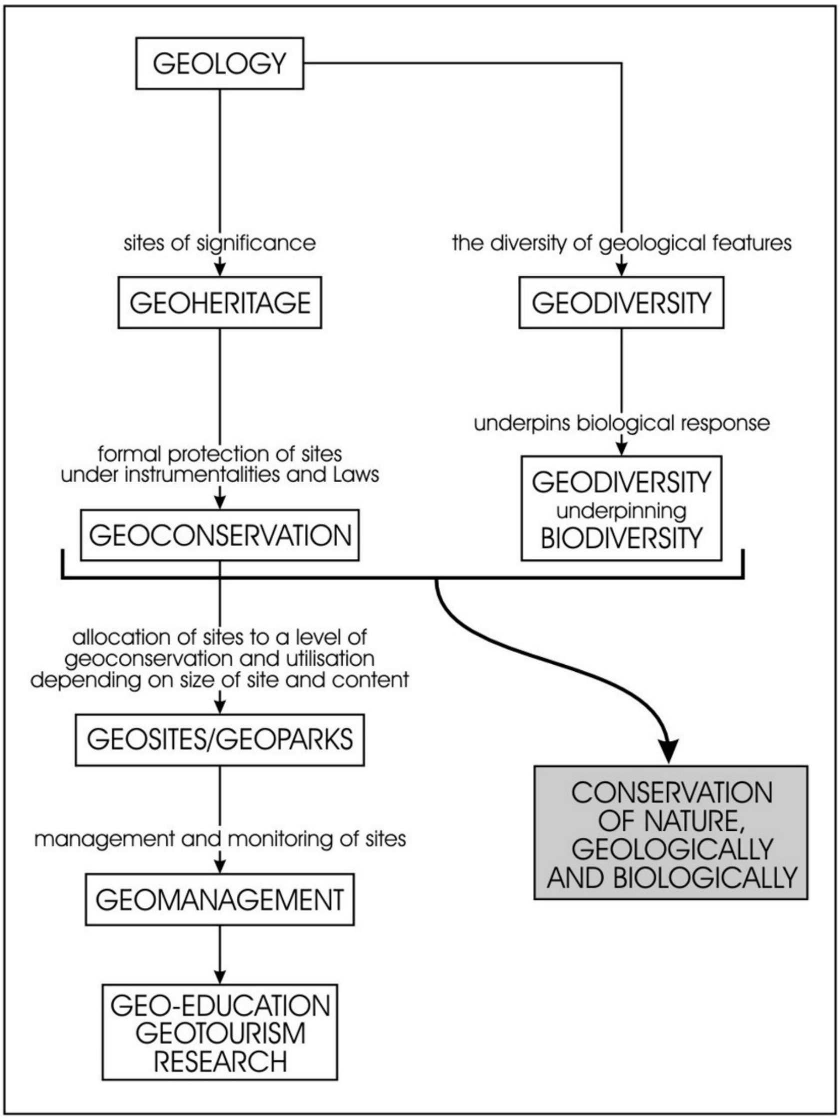

Figure 1. Progression of the 8Gs (from Brocx & Semeniuk, 2019).

Geology has a dual meaning – *Geology* is the discipline of the study of the Earth but also denotes all abiotic features of specific areas. *Geodiversity* is the diversity of geological features in a given area. A given region may have high geodiversity with a plethora of lithologies, their weathered products, faults and fractures, structures such as folds, and a variety of mineral species and a rich fossil diversity, or it may be of low geodiversity (*e.g.*, a thick sequence of a structurally simple, relatively uniform lithology, *e.g.*, quartz sandstone). *Geoheritage* is the legacy of geological features, seeking to evaluate/recognise significant features through identification-categorisation-and-evaluation, ultimately for their preservation. *Geoconservation* seeks geological preservation through various instrumentalities. Identification of a site or sites of geoheritage significance may require their inscription for conservation as a *Geosite*, or as an ensemble of sites in a *Geopark* [1,2,3]. Once the value of a geological feature assessed as being of significance and identified as a geosite or geopark, prior to its use as a site for Education, Reference, Research, or Tourism, its physical/chemical vulnerability and ability to sustain frequent visitors and/or collecting, or its risk as a hazard has to be ascertained, and management plans need to be designed [1,4,5]. Thus, *Geo-management* needs to be pursued prior to any use of the site(s) for Geo-education and Geotourism to ensure latter endeavours do not degrade or diminish the site though indiscriminate trampling, collecting, or anthropogenically-induced changes to the environment (*e.g.*, within caves).

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SESSION 6: DIGITALISATION OF GEOLOGICAL HERITAGE

Convener: Isabelle Rouget

Low-cost sensor networks for geoheritage protection: challenges and solutions for real-time cave monitoring (Invited Keynote)
Mendez N., García-Saura C.

XRCave - Augmented Reality in Caves
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Valorization of Cava Porcili (Apulia, southern Italy): 3D models for the study and recovery of an abandoned quarry
Lippolis, E., Spalluto, L., Sabato L., Tropeano, M.

Digital La Pedriza, integrating educational objectives, geoconservation, and sustainable development. the role of the website and Instagram of UNESCO
López Portillo H.

Enhancing Underground Cultural Heritage: Muography and LIDAR for Integrating Geology, Archaeology and Architecture
Melelli L., Borselli D., Marconi L., Beni T., Fanò L., Stoppini A., Bonechi L., Radicioni F.

The Italian Geosites Inventory: Technologies for consultation and conservation
Primerano P., Brustia E., Congi M.P., Funaro M., Guarino P. M., Lucarini M., Olivetta L., Pompili R., Vitale V.

Geomorphological mapping for geoheritage protection and valorisation: the digital database of the Adamello Brenta UNESCO Global Geopark (European Alps)
Seppi R., Scognamiglio E., Zanoner T., Carton A., La Licata M., Masè V., Viviani M., Zumiani M., Viganò A.

Geoscience popularisation in Geoparks: A Common Workflow for Digital Outcrop Modelling from the “3GEO” IGCP 714 Project
Williams M.A., Tronti G., Sartori Peruzzo R., García-Rodríguez M., Fazio E., Zucali M., Bollati I.M.

INVITED KEYNOTE

Low-cost sensor networks for geoheritage protection: Challenges and solutions for real-time cave monitoring

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Geoheritage sites represent crucial components of the earth natural system, encompassing unique geological features, fossil localities, mineral occurrences or landscapes, among many other elements with a significant scientific, educational or cultural value. Protecting these sites from deterioration, vandalism, environmental impact or even unauthorized activities poses significant challenges, especially in remote locations with limited surveillance resources. This scenario requires cost-effective and scalable monitoring solutions to ensure sustained preservation of the sites.

However, remote sensing has traditionally been limited by the complexity and intricacies of the monitored environments. The lack of real-time connectivity in remote areas (i.e. when deploying sensors in caves), has the specific problem where frequent field-trips are necessary and it takes a long time -and risk of accidents in intricate cave systems- to retrieve the data loggers. And whenever sensors fail, it takes until the next visit for issues to be detected and repaired, but a lot of data is lost in the process. So real-time communications and rapid detection would be very beneficial in these cases.

We explored the potential and application of low-cost IoT (Internet of Things) sensor networks as innovative and affordable tools for geoheritage protection. Sensor networks consist of multiple sensor nodes capable of monitoring various environmental parameters, including temperature, humidity, vibration, seismic activity, visitor traffic and access. Advances in electronics and wireless communication protocols have significantly reduced the cost of sensors and infrastructure, making these networks viable and effective for widespread development and deployment.

In particular, the decreasing costs of wireless microcontrollers (ESP32, BK72, RTL87), sensors (accelerometers, humidity, temperature, gases, presence sensors or even cameras), energy efficient transmission protocols (WiFi, ZigBee, LoRaWAN, BLE) and solar powered solutions have democratized sensor deployment, enabling researchers and site managers to establish highly effective and comprehensive monitoring networks at a fraction of the cost.

Developing a conceptual framework for designing and deploying sensor networks tailored specifically for geoheritage protection is fundamental and must be able to allow choosing appropriate sensor types based on site-specific risks and conditions, designing efficient network topologies that reduce transmission problems and choosing suitable wired and wireless communication protocols. Additionally, the deployment strategies must emphasize modularity and scalability, allowing gradual network expansion and ease of installation. The set up of solar power and battery backups ensures uninterrupted monitoring even in remote and off-grid locations.

One of the cases we have studied more in depth is the use of PoE (Power Over Ethernet) technology for deploying sensor networks within cave networks, where wireless signals are obstructed, and power sources and timing signals are challenging to manage. The PoE approach is able to provide simultaneous data communication and electrical power via standard ethernet cables, significantly simplifying installation and maintenance. This approach allows sensor nodes, such as temperature, humidity or gas detectors to be strategically placed deep within caves, powered only by a single cable run from the cave entrance or a surface installation.

Cave systems are very sensitive environments and are particularly vulnerable to both anthropogenic [1] and natural changes. Natural causes such as flooding, seismic events, rockfalls and microbial activity can significantly alter cave interiors, affecting delicate geological formations and ecosystems. Human induced damage, including common visits, unauthorized access, vandalism, littering and the alteration of cave climate through excessive visitation and contamination, further exacerbate these challenges and the need for constant monitoring inside the caves.

Also, there is the case for touristic caves, where several criteria must be met in order to ensure the safety of visitors, such as oxygen content, temperature, humidity or even radon concentrations [2]. So, to allow safe visits, there is also a need for continuous monitoring of the environmental quality of cave environment and alert in case any thresholds have been exceeded.

Furthermore, the PoE approach can efficiently support higher-bandwidth requirements for real-time transmission of more sophisticated sensors such as seismometer or piezoelectric vibration sensors for microseismicity and rockfall detection [3], and even full video/audio streams. Supporting these advanced sensors has the potential to enable the early detection of relevant threats such as environmental disturbances, structural instability or rapid response to trespassing.

Essential to the process are the data management and analytics that allows management to take any necessary measures over the possible alerts. We address efficient data collection, storage, transmission and interpretation mechanism using the open-source solutions "Home Assistant and ESPHome", that allow to easily create a dashboard tailored for each final user, to access data and alerts and even receive notifications in several devices simultaneously. Real-time analytics can detect anomalous events, such as sudden temperature variations and ground vibrations indicating unusual visitor activities, triggering immediate notifications for a rapid response (see Figure 1).

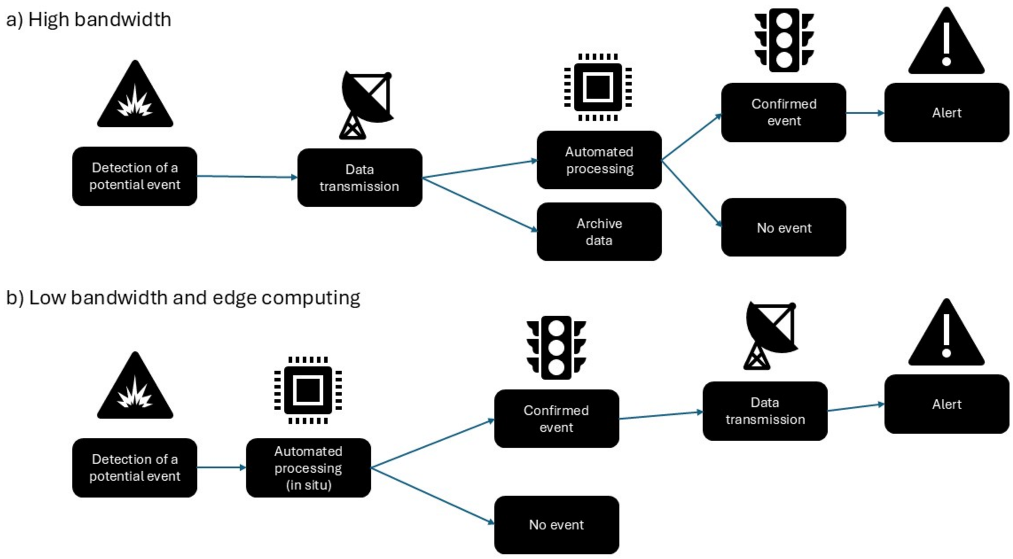

Figure 1. Different cases of alert triggering based on the bandwidth and computing power.

Real time analytics and automated rules play a crucial role to promptly respond to any changes. The development of small and efficient machine learning models optimized for edge computing can also allow the fast detection of anomalies and the classification of events on-site. These lightweight algorithms require minimal computational resources, enabling a rapid decision-making process without latency, which can be particularly beneficial in remote areas or caves where immediate action is necessary.

Among the challenges and limitations for the low-cost sensing approach are network reliability, maintenance requirements or even potential vandalism to the sensors themselves. Solutions like redundancy in network connectivity or electric power, robust protective casings and open design can be studied case-by-case to address these changes in an effective manner.

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XRCave - Augmented Reality in Caves

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Extended Reality in Caves (XRCave) is a project that aims to integrate Augmented Reality as a multipurpose tool for research, management and dissemination of the underground environment and its heritage. This work presents the beta-phase project that took place in Gruta de las Maravillas (Aracena, Southwest Spain), a show cave with more than 200.000 visitors yearly. Using an Augmented Reality App, installed on a Smartphone or Tablet device (Fig. 1A), the geological heritage of the cave can be interpreted and easily explained to any user or viewer. The app uses a combination of geomatic data, such as LIDAR, photogrammetry, and geological, geomorphological and hydrogeological data, that is combined during the post-processing phase, in order to represent the processes, shapes and elements that contribute to the current architecture of the cave. By introducing this data to the app, everyone can interact in real-time with the cave, highlight the different elements (Fig. 1B) and even simulate the evolution of the cave, selecting the different phreatic levels, the growth of speleothems and highlight the different generations grown along the evolution of a cave.

Figure 1. Left: Using a smartphone, the real-time video data can be seen, as well as a layer that represent the water-table in different time moments. Right: User interface of the App, with some of the elements that can be represented, with only one layer selected.

The app is designed to be used offline, so that once inside the cave, the user will be able to point the equipment towards the formations (speleothems, walls or even ceiling) and have the option to see, projected on top of the video stream layer, several layers of graphic information that will aid us in the identification of speleothems, as water tables, lava flows, stalactites, stalagmites, gours, flags, and others. The graphic layers can be activated or deactivated, as well as their opacity, that can be adjusted. That allows the user to see through, allowing the identification of different generations or also non-visible shapes that would otherwise be difficult to differentiate for the average visitor. The objective is to apply this technology in cave visits, aiding in the interpretation of the geological heritage, the cave elements and structures, as well as providing a more accessible and comfortable experience to those visitors who may need them. This augmented reality system is based directly on the geological data provided by experts, who need to take an on-hand approach, designing geomorphological sections specific for this use, highlighting the more important elements to be represented, and identifying the evolutionary sequence. This data can also be combined with concrete data such as dating, environmental parameters, or even technical data used for management, such as the location of electric wires. As the geomatic data that is needed is non-invasive (Fig. 2A), no physical harm is done to the cave, allowing the use of this technology in vulnerable or non-visitable areas of the cave (Fig. 2B). XRCave is the result of an agreement between the Spanish Geological Survey, the Spanish Show Cave Association, Aracena Town Council, Gruta de las Maravillas and Cinemedia & Heritage S.L.

Figure 2. Left: This technology can be used to improve the accessibility of the cave, by showing the visitors parts of the cave that are usually not shown. Right: The base layers are made using LIDAR, adding photogrammetry on top, leaving no harm to the natural surface and only using non-invasive techniques.

Valorization of Cava Porcili (Apulia, southern Italy): 3D models for the study and recovery of an abandoned quarry

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The Apulian territory (southern Italy) is rich in limestone quarries, used since ancient times to extract and produce materials for both modern and traditional construction and architecture. Cava Porcili is one of the most famous limestone quarries located south of the town of Minervino Murge (Apulia, southern Italy), and falls within an area of an aspiring UNESCO Geopark. This quarry, which is currently abandoned, have a great educational, scientific and touristic potential thanks to the presence of many interesting geological features such as: a 80 meters thick succession of shallow water Cretaceous limestone which shows a spectacular Milankovitch cyclicity and some syndepositional slumps; Tertiary normal faults with a well identifiable displacement thanks to the presence of some lithostratigraphic markers within the Cretaceous succession; five karstic caves included in the list of Apulian geosites; Quaternary slope debris linked to the most recent normal fault. This quarry is not yet a geosite but it has all the characteristics to become one of the pillars of the MurGEopark; in fact, it could become an open-air museum or a starting point for geotouristic trails in the area. This research made it possible to study the outcropping succession in detail, increasing geological and stratigraphic knowledge of the area, and to create 2 different 3D digital models, using the UAV photogrammetry technique.

The quarry is currently inaccessible and the 3d models represent to date the only way to study in detail Cava Porcili. In this quarry, older, limited photographic documentation fails to provide comprehensive coverage. A 3D model fills these gaps, offering an important tool for studying geology in three dimensions, preserving and making the quarry known to a wide public, also making it virtually accessible, waiting and hoping for full future fruition.

Digital La Pedriza, integrating educational objectives, geoconservation, and sustainable development. The role of the website and Instagram of UNESCO geoclimbingspain in Secondary Education

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This work presents how the digitization of Geological Heritage has constituted a tool for integrating the goals of UNESCO IGCP 714 3GEO Geoclimbing & Geotrekking in Geoparks, the Geosites Project, UNESCO Biosphere Reserves, Sites of Geological Interest (LIGs, in Spanish), Protected Natural Areas in Spain, and Sustainable Development, with the acquisition of the 6 specific competences of the Sciences in Secondary Education in Spain.

Introduction

OBJECTIVES OF UN AND UNESCO INTERNATIONAL FIGURES

The United Nations was founded in 1945 to promote Human Rights. The current Secretary-General took office in 2016 stating, "In the end, it all comes down to values" [1]. Human dignity will be "the core of my work." The UN's work is based on 17 Sustainable Development Goals (SDGs).

UNESCO is dedicated to promoting education, science, culture, and communication. It sets standards, produces tools, and develops knowledge to foster a world of greater equality and peace, based on the intellectual and moral solidarity of humanity

UNESCO Biosphere Reserves seek solutions for biodiversity conservation and the sustainable use of resources.

The Global Geosites Project, promoted by the European Association for the Conservation of the Geological Heritage (ProGEO) and the International Union of Geological Sciences (IUGS) with the co-sponsorship of UNESCO [2] (IGME n.d.), seeks to promote "geoconservation" by declaring geological sites of interest (geosites). These geosites serve, among other goals, for research and education.

The UNESCO International Geoscience Programme (IGCP) promotes collaborative projects for the benefit of society based on the exchange of scientific knowledge [3].

The IGCP 714-3GEO-Geoclimbing & Geotrekking in Geoparks project aims to provide "innovative tools for communicating geosciences through geoclimbing and geotrekking; produce 3D models of specific geological heritage sites in different countries and develop complementary multimedia educational resources for both schools and the general public" [4]. The Spanish IGCP 714 working group was established in Madrid in May 2021 [5].

OBJECTIVES OF THE SITES OF GEOLOGICAL INTEREST BY THE SPANISH GOVERNMENT

Law 42/2007 mandated the creation of the Spanish Inventory of Sites of Geological Interest (LIGs). The need for the conservation of geological sites of interest was based on their importance for science and education [6]. Other types of interest such as cultural, recreational, and scenic were also considered (IGME 2019).

OBJECTIVES OF THE PROTECTED NATURAL AREAS IN SPAIN

A National Park is a natural area that, due to the uniqueness of its flora, fauna, or geomorphological formations, has general interest for the nation. Its objective is to ensure the conservation of its natural values.

OBJECTIVES OF BIOLOGY AND GEOLOGY AT THE SECONDARY EDUCATION STAGE IN THE COMMUNITY OF MADRID, SPAIN

The subject of Biology and Geology seeks to develop curiosity and scientific culture. It aims to encourage values of commitment, respect, solidarity, and teamwork, as cooperation is an essential part of scientific methodologies. It also aims to promote, especially among female students, scientific vocations, and the social

integration of diverse people. It should ensure that students use different formats and channels to communicate and cooperate, including virtual workspaces [7].
The specific competences, summarized, are:

1. Interpret and transmit scientific information and data using different formats, to analyze concepts and processes of biological and geological sciences.
2. Identify, locate, and select information to answer questions related to biological and geological sciences.
3. Develop research projects following scientific methodologies and cooperating to investigate aspects related to geological and biological sciences. This competence is related to the STEM competence.
4. Use reasoning and computational thinking, critically analyzing responses and solutions to solve everyday problems related to biology and geology.
5. Analyze the effects of certain actions on the environment and health, based on Earth sciences, to promote habits that avoid negative environmental impacts and are compatible with sustainable development.
6. Analyze elements of the landscape using knowledge about geology and Earth sciences to explain its geological history, propose actions aimed at its protection, and identify potential natural hazards.

The mathematical competence and competence in science, technology, and engineering (STEM competence) involves understanding the world using scientific methods, mathematical thinking and representation, technology, and engineering methods to transform the environment in a committed, responsible, and sustainable way [8].

Description of La Pedriza

La Pedriza, located on the southern slope of the Sierra de Guadarrama (Madrid, Spain), is a landscape recognized for its beauty, geomorphological diversity, and its fauna and flora. Its unique geology includes crests, dome-shaped and bell-shaped formations, rocky outcrops, gravel areas, slabs, and sand areas. It is included in the National Parks Network, is not listed as a "Global Geosite," and contains 11 Sites of Geological Interest (LIGs).

Digitization of Geological Heritage as a tool to integrate educational, geoconservation, and Sustainable Development Objectives

Digitization, understood in a broad sense, is the process of transforming physical objects into digital ones. It also includes cloud storage of digital files for their use.
The educational use of digitized geological and natural heritage facilitates research, allows students to explore geology and ecosystems in an interactive and participatory way, fosters awareness and protection of geological and biological heritage. It contributes to sustainable development and the achievement of the SDGs.
SDG3. Health and Well-being: Promotes respectful and enjoyable outdoor activities that contribute to physical and mental well-being.
SDG4. Quality Education: allows access to up-to-date content, promotes multidisciplinary and flexible learning.
SDG5. Gender Equality: The globalization of internet use, including mobile phone use, facilitates women's access to information, communication, and research, helping to reduce the gender gap in sciences.
SDG9. Industry, Innovation, and Infrastructure: drives innovation and provides new tools for the sustainable management of resources.
SDG11. Sustainable Cities and Communities: The study of geological heritage promotes the integration of valuable environments in territorial planning and awareness of geological risks.
SDG13. Climate Action: The digitization of geological heritage helps assess climate change and develop response strategies.
SDG15. Life on Land: promotes the study and protection of terrestrial ecosystems.
SDG17. Partnerships for the Goals: Promotes collaborations between educational institutions, governments, and international organizations, which are key for knowledge exchange and sustainability promotion.

Methodology

The work presented is based on the digitization of geological and natural data from the La Pedriza area of Manzanares del Real, and its publication on the UNESCO geoclimbing Spain Instagram and the virtual classroom of the CEPA Paulo Freire Public Secondary Education Center in Fuenlabrada. This work had a dual

objective:
- Create materials for the IGCP 714 3GEO Geoclimbing & Geotrekking in Geoparks Project.
- Enrich the content of the Natural Sciences virtual classroom at the CEPA Paulo Freire Public Secondary Education Center, so that students from the four classes at level 1 of secondary education studied Geology and Biology, and applied what they learned by conducting participatory research on La Pedriza.

To perform the digitizations, various techniques, equipment, and materials were used, including some data digitized using climbing techniques. These included photographs, conventional videos, 360 videos, 3D models obtained with LIDAR scanners from tablets or iPhones, and thermal images obtained with a thermal camera. Additionally, photographs of invertebrates (in situ) and microphotographs of microorganisms from water samples from La Pedriza were obtained.
The educational process also used various digital resources, including the UNESCO geoclimbing Spain website, iNaturalist (for the identification of lichens, mosses, higher plants, and invertebrates), Plantnet, and Google Lens.

Results
The educational use of digitizations and the work carried out within the framework of the UNESCO IGCP 714 3GEO Geoclimbing & Geotrekking in Geoparks Project in the virtual classroom of the CEPA Paulo Freire in Fuenlabrada allowed CEPA Paulo Freire students to:
- Learn about UNESCO, UNESCO IGCP 714 3GEO Geoclimbing & Geotrekking in Geoparks, and the activities of the Spanish group, UNESCO geoclimbing Spain.
- Use digital media and digitizations in the secondary school classroom to address a multitude of topics related to Natural Sciences, mountain sports, geoclimbing, new technologies, and research.
- Deepen their knowledge on various topics from the syllabus.
- Conduct research on La Pedriza: geology, biology, rocky habitats, impacts of leisure and sports activities, including climbing. They studied the interrelationships between geological and geomorphological elements and biological ones. They developed trophic chains identifying: Bacteria, protozoa, fungi, bryophytes, higher plants, invertebrates, amphibians, reptiles, fish, birds, and mammals. They learned about siliceous speleothems from La Pedriza.
- They published comments on the scientific Instagram UNESCO geoclimbingspain.
- They prepared two posters that were presented at two important secondary education conferences:
    - ✓ I Congress of Education towards Sustainability, CEPA Paulo Freire exploring and acting. Educating for biodiversity. Sustainability in the educational field. PLANET. Biodiversity: preservation and restoration, May 31 and June 1, 2024, General Directorate of Bilingualism and Teaching Quality, Ministry of Education, Science, and Universities of the Community of Madrid"
    - ✓ STEM Madrid Congress "Studying vulnerable rocky habitats of La Pedriza de Manzanares in 3D and 360. STEAM and PBL methodologies. Studying the Geology and Biodiversity of La Pedriza de Manzanares del Real with 3D models and 360 videos, we addressed the contents of Natural Sciences in a practical and fun way, developing technical, creative, individual, and teamwork skills¨, November 6, 2024.

Five students represented the four classes of level 1 of Natural Sciences in the public exhibition of the second poster. They explained to students and teachers from 63 other centers, and to the jury of the Community of Madrid: what the STEAM and PBL methodology had contributed to their comprehensive academic training; they justified how they had integrated Sciences (Geology and Biology), technologies, mathematics, and project-based learning; the geology and biology of La Pedriza; the technological skills acquired during the course, as they themselves created 3D models with iPhone mobile phones, used the thermal camera, an endoscopic camera, and an ultrasound detector with which they identified fissure-dwelling bats in the CEPA courtyard; the interest in using photos, videos, 3D models, 360 videos, and publishing on UNESCO geoclimbing Spain Instagram and iNaturalist; the apps they had used for their research; the scientific method used in their research on La Pedriza (introduction, hypothesis formulation, objectives, methodology, results, threats and solutions, conclusions, and bibliography).

Figure 1. A. Equipment used for digitization in the work: endoscopic camera, Hikmicro thermal camera for mobile phone (accuracy 0.05º C); Echometer Touch 2 ultrasound detector for surveying bats; mobile microscopes 250X, handheld thermal camera. B. Greater noctule detected in La Pedriza. C. Siliceous speleothems microgour in La Pedriza. D. 3D model obtained with an iPhone 12 Pro. E. Hypnum cupressiforme and Hedwigias in La Pedriza. F. Cladonia and beneath Syntrichias.

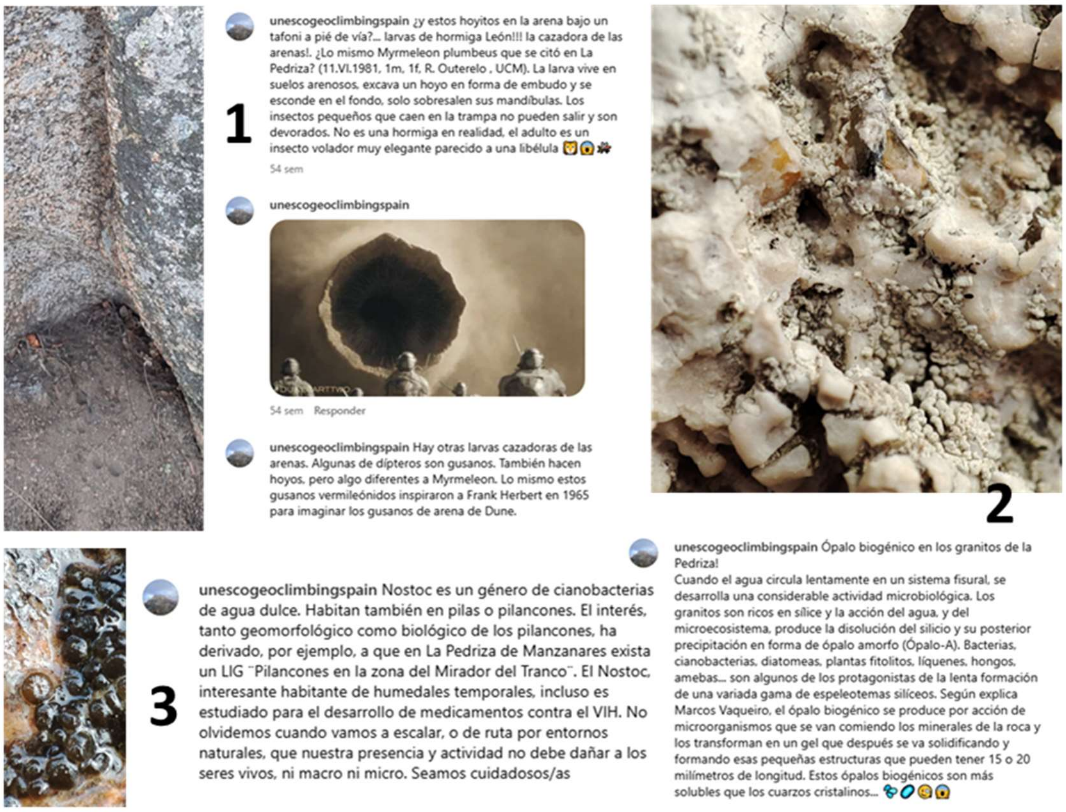

Figure 2. Examples of posts on the UNESCO geoclimbingspain Instagram; the first about the antlion that lives under a tafoni (Myrmeleon plumbeus), the second about biogenic opal in the granites of La Pedriza.

Figure 3. Images of the two posters presented at the Congresses of the Community of Madrid, and of a post related to the STEM Madrid Congress shared on the networks of the Fuenlabrada City Council, Carlos III University, CEPA Paulo Freire of Fuenlabrada, on the UNESCO geoclimbingspain Instagram

Conclusions

The digital materials generated within the framework of the IGCP 714 3GEO Geoclimbing & Geotrekking in Geoparks Project, and their use in the Virtual Classroom of Secondary Education, demonstrate the benefits of group research on complex problems, and their utility for proposing solutions to problems related to the conservation of geological and biological heritage. The sensitization capacity of digitizing natural environments demonstrates the potential and importance of sharing knowledge.

The work carried out for UNESCO IGCP 714 3GEO Geoclimbing & Geotrekking in Geoparks has served to achieve the objectives of the Geosites Project, UNESCO Biosphere Reserves, Sites of Geological Interest (LIGs), Protected Natural Areas in Spain, and Sustainable Development, and the acquisition of the 6 specific competences of the Sciences in Secondary Education in Spain. The Digitization of Geological Heritage and the "Virtual Classroom" have been the tools.

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Enhancing Underground Cultural Heritage: Muography and LIDAR for Integrating Geology, Archaeology and Architecture

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The subterranean architectural and archaeological heritage is related to the geological configuration that characterises the specific location [1]. In urban and peri-urban areas, it is imperative to consider not only the pre-settlement geological environment, but also to reconstruct the changes that have occurred over the centuries as a result of human activity. [2]. For this reason, it is crucial that the approach to identifying underground cultural heritage is interdisciplinary; in addition, this resource is not always accessible due to logistical constraints. The challenges associated with identifying and surveying ancient subterranean sites are primarily attributed to the scarcity of documentation, which often makes their precise locations elusive, and even when these locations are identified, accessibility constraints may further limit exploration. There is a possibility that sites might become inaccessible for a number of reasons, such as being covered by material that has accumulated over time as a result of anthropogenic activities. Additionally, the original access routes may have been destroyed by natural processes, including the gradual accumulation of debris, such as landslides. Furthermore, even when access is granted, it may be restricted due to their location on private property or the necessity of specialised personnel to accompany visitors due to security concerns.
However, the subterranean heritage offers, due to its location, intriguing and unique insights that facilitate multidisciplinary integration among related disciplines such as geology, archaeology and architecture. This is advantageous for both research and educational purposes, as well as for the promotion of tourism.
The availability of novel techniques enabling remote identification and digital capture of these species can be pivotal to facilitate their study and subsequent conservation efforts. In order to preserve the integrity of the sites under investigation it is imperative to employ non-invasive methodologies.
Geomatics techniques facilitate the reconstruction of subsurface models, providing three-dimensional representations that underpin archaeological research. Among the most frequently employed tools for this purpose are GNSS (Global Navigation Satellite System) networks, which are instrumental in defining a framing network necessary for the relative three-dimensional positioning of architectural elements. Laser scanning LiDAR (Laser Imaging Detection and Ranging) is capable of measuring distances and angles in large quantities and in a very short time and collecting a cloud of georeferenced points [3]. Meanwhile, digital terrestrial and drone photogrammetry, linked to the acquisition of high-resolution images, allows for the 3D reconstruction of hypogean and epigean environments and more generally of topographical surveys. Georadar and geophysical surveys also contribute to the modelling of the subsoil. The use of the tools listed above is already well established and widespread in the scientific community. Recently, a new remote acquisition technique has been making the headlines in geology, archaeology and architecture: the muon radiography. The muon is a charged particle with a high ability to penetrate matter. Atmospheric muons, produced by the interaction of primary cosmic rays with the Earth's atmosphere, are the most penetrating charged particles and among the few that reach the Earth's surface. The transmission muography technique employs the penetrating power of atmospheric muons to generate a non-invasive transmission image of a target. This method has been employed to monitor the interior of large structures, including mountains, pyramids and volcanoes.
This paper presents two case studies in which LiDAR and muon radiography techniques have been used for the identification and enhancement of underground sites.
The first case study relates to the Villa del Colle del Cardinale, an important historical residence located near the city of Perugia (central Italy). The complex is the most renowned Umbrian residential complex, built in the second half of the 16th century by Cardinal Fulvio della Corgna, nephew of Pope Julius III. The villa's design is thought to have been overseen by Alessi (architect 1512-1752), and it is surrounded by a large park with secular trees and hanging gardens. The interior is embellished with intricate "grotesque" decorations, a

precious wooden coffered ceiling, and a fresco cycle depicting the Arts and Virtues, painted in 1581 by the Florentine artist Salvio Savini.
The central building is situated on a basement level, which comprises several rooms, some of which are decorated with frescoes and contain architectural singularities that are the subject of ongoing study. Due to logistical constraints relating to safety concerns, access to the basement levels of the villa is currently restricted. As part of a project to disseminate the naturalistic and geological values of the villa and the park surrounding it, a mobile application called HUSH (Hiking in Urban Scientific Heritage) was developed with content of an artistic, architectural, geological and naturalistic nature. For the former, the most valuable rooms located in the basement of the Villa were digitised by laser scanning technique. The outcomes of this process are illustrated by Figures 1 and 2, which depict the "Bagno del Cardinale" and the "Salle à mange" rooms, respectively.

Figure 1. The Digital Twin of the "Bagno del Cardinale" room: on the left a frame of the video uploaded in HUSH mobile application.

The utilisation of Digital Twins within the mobile application facilitates virtual exploration of the subterranean rooms, despite the possibility of physical access being disallowed. The contents include static images and navigable 3D models. Moreover, Digital Twins can be utilised for technical and scientific analyses of the structure to estimate its stability. This includes an assessment of cracking conditions and/or damage to frescoes and wall structures caused by mould and moisture.

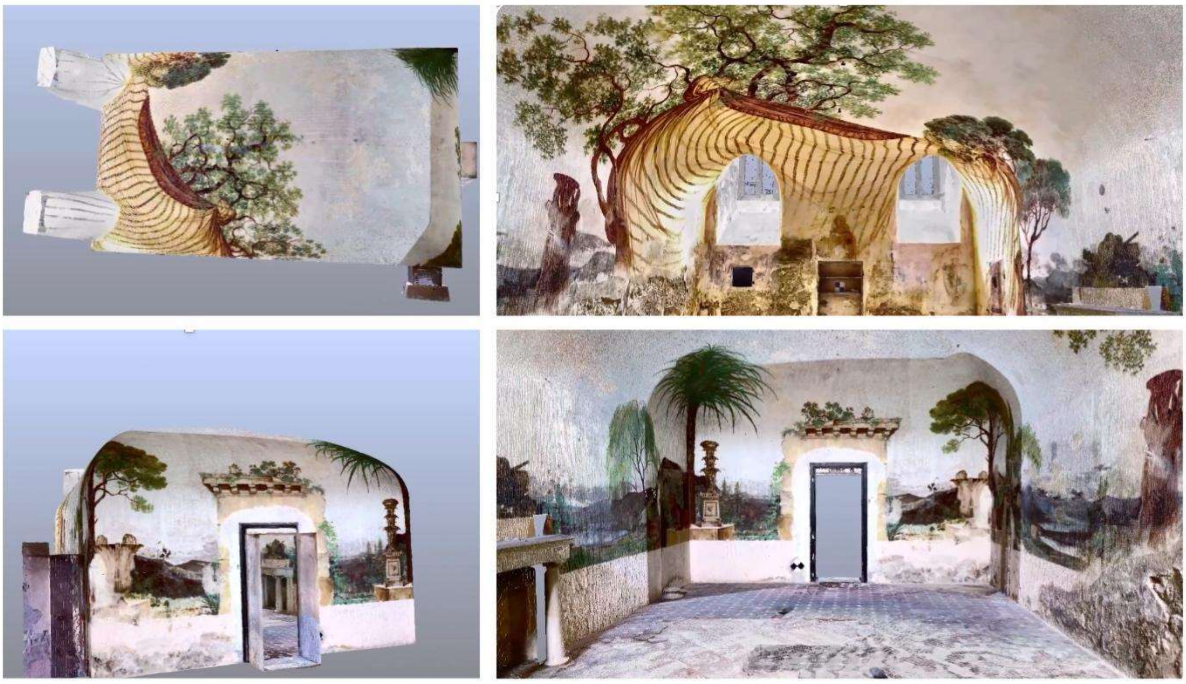

Figure 2. The Digital Twin of the “Salle à manger” room how it appears in several frames of the video uploaded in HUSH mobile application.

The second example shows the results obtained using muon radiography in the Etruscan Necropolis of Palazzone (Perugia). In the Palazzone Necropolis approximately two-hundred Etruscan tombs are present dated from the Hellenistic period with five from the Archaic era. The necropolis is also classified as an archaeo-geosite [4]. This is since the tombs' walls, where the natural terrain outcrops, have been the subject of geological studies. These studies have contributed to a broader understanding of the geological and geomorphological evolution of the hill on which the city of Perugia is located. However, additional tombs may exist, particularly in the eastern section of the site, which remains closed to visitors. The topographical conditions and the dense vegetation covering this part of the necropolis make it difficult to locate hypothetical tombs using other geomatic methods. In addition, many of the entrances have collapsed over time, making fieldwork difficult (Fig. 3a).

In this context, muography, leveraging the high penetrating power of atmospheric muons, provides a non-invasive method for detecting hidden cavities. In this project the MIMA (Muon Imaging for Mining and Archaeology) tracker has been used (Fig. 3b) in a joint project between the Florence INFN Division and the Department of Physics and Astronomy of the University of Florence and the University of Perugia with the Regional Directorate of Museums of Umbria (Italian Ministry of Culture).

The instrument was installed inside the Necropolis in the storage and office rooms. The location showed an optimal angle for recording the muon flow across most of the slope under investigation. The MIMA was installed on 13 May 2022 and the signal was acquired continuously for 58 days. Some low-density regions have been identified as potential sites for cavities. The findings are also integrated into a geological framework to assess the densities of sediments present in the area [5].

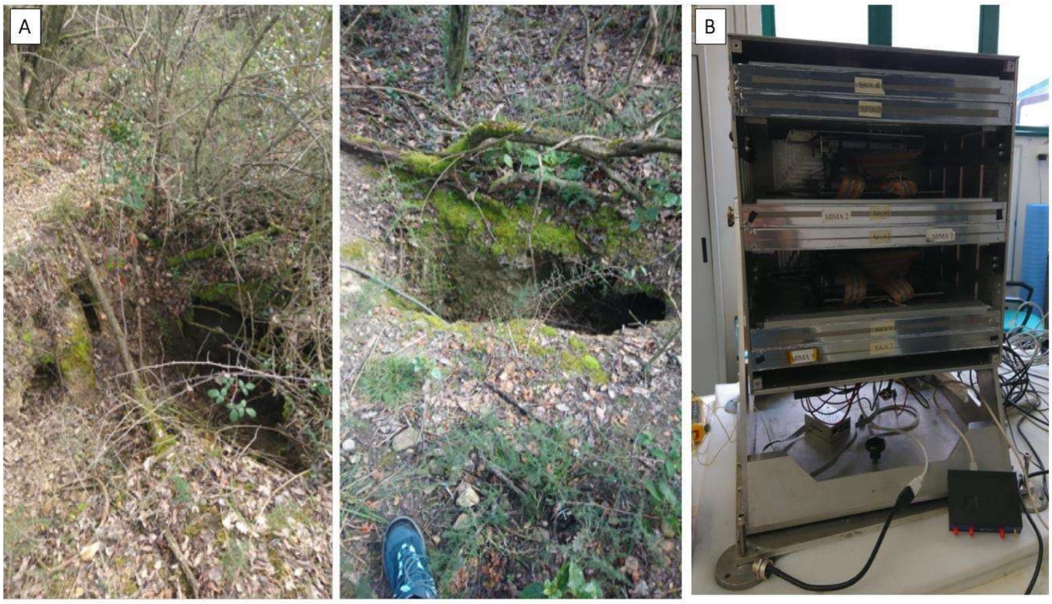

Figure 3. A) Potential traces on the ground of tomb entrances on the slope investigated with muon radiography; B) the MIMA muon detector.

The article's conclusions draw on a comparative analytical approach, which is used to explore the various techniques that have been employed in the field of remote sensing of the subterranean geoheritage, in particular for sites of transdisciplinary value, where geology is the starting point for attracting and involving other disciplines.

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The Italian Geosites Inventory: Technologies for consultation and conservation

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As part of the activities planned by the PNRR GeoSciencesIR project, the database of the National Inventory of Geosites [1] will be enhanced and harmonized according to the FAIR principles (Findability, Accessibility, Interoperability, and Reuse) for data sharing. A core set of information conforming to the INSPIRE principles will also be published. The main objective of the project is to provide, to as many users as possible, information about the geosites located across the national territory.

To enrich the database [2], which will be shared in a standardized format to facilitate consultation, three-dimensional digital models of selected geosites of the inventory will be integrated into the research infrastructure planned by the project, through which users will be able to take virtual tours.

By using a combination of laser scanning, LiDAR, and photogrammetric surveys, also by drone, digital scans of the geosites of the Campo Soriano Natural Monument (LT), the Mohorovicic Discontinuity of Premosello (VB) and the Piana Crixia Fungus (SV) have been acquired. The point cloud processing was carried out using the "MAGNET Collage" and "Agisoft Metashape" software.

Following the description of the geosites chosen to enrich the database content:

- The outcrop of the Mohorovicic discontinuity (VB) is a geosite of national interest. The outcrop located In Premosello district shows the contact between lithospheric mantle rocks and the lower continental crust (Fig. 1). The mantle is represented by a serpentinized peridotite, in the lower part of the outcrop; the lower crust is represented by a mafic granulite, part of the Mafic Complex of the Ivrea-Verbano Zone, in the upper part. The contact surface represents the Mohorovicic discontinuity, marking the transition from upper mantle to lower crust [3]. At Premosello the Mohorovicic discontinuity appears to have been brought to surface through exhumation processes occured during the subsequent Alpine orogeny. The geosite has been even included among the 200 geosites of greatest scientific interest worldwide according to the International Union of Geological Sciences (IUGS) [4];
- The 'Fungo' of Piana Crixia is located in the southwest of the Piana Crixia village (SV). It is in the central portion of a rocky escarpment, which represents the eroding bank of a meander of the Bormida di Spigno river. The geosite consists of an 11-meter-high truncated-conical column of conglomerate, topped by a 5-meter-diameter serpentinite boulder (Fig. 2. The estimated weight of the serpentinite block supported by the column is over 100 tons [5];
- The Campo Soriano Natural Monument (LT) is a geosite of national interest within a karst field and consists of a *hum* that represents a relict portion of an eroded limestone plate [6]. The area is protected and classified as a Natural Monument with primary scientific interest of a geological nature (Fig. 3)

As part of the activities carried out at the Campo Soriano geosite, it was possible to monitor the evolution of the geosite. By comparing point clouds acquired using the same methodology in different times, it is possible to determine the erosion rate to which the rock mass is subjected, identify critical discontinuities, and quantify the size of unstable blocks. Based on this analysis, it is possible to mitigate the natural degradation. Thanks to the high resolution of the point clouds acquired on-site, it was also possible to create scaled models using 3D printing.

The implementation of the consultation of the National Inventory of Geosites, also by laser scanning technologies, could give an important contribution to the enhancement and monitoring of the Italian geological heritage.

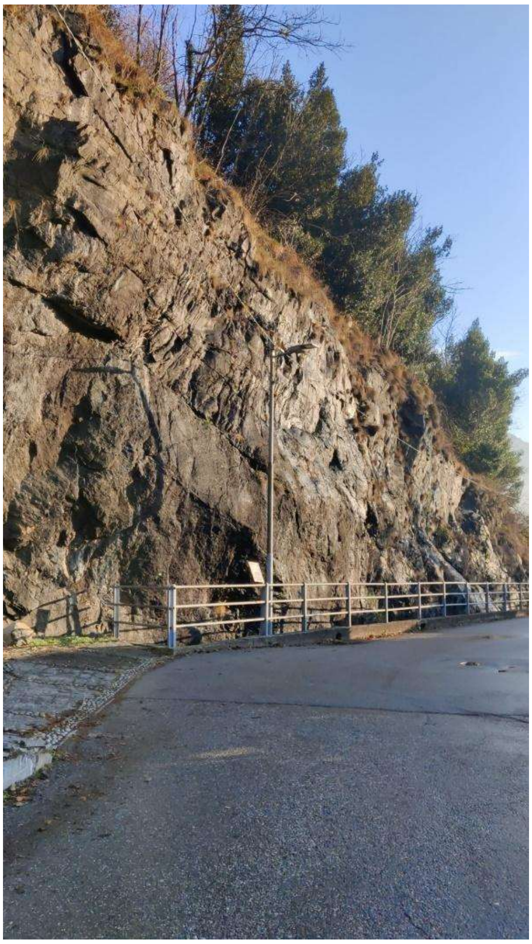

Figure 1. The Mohorovicic discontinuity (VB).

Figure 2. The 'Fungo' of Piana Crixia (SV).


Figure 3. The Campo Soriano Natural Monument (LT).

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Geomorphological mapping for geoheritage protection and valorisation: the digital database of the Adamello Brenta UNESCO Global Geopark (European Alps)

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Introduction

Geomorphological maps are key tools for representing the physical features of the landscape and the processes that control its evolution [1]. In addition to their undeniable scientific value, geomorphological maps play an important role in territorial planning and sustainable environmental management. Especially in Protected Areas such as UNESCO Global Geoparks (UGGps), geomorphological maps are essential for better understanding landscape evolution, emphasizing sites of high educational and touristic value, and identifying areas potentially exposed to geomorphological hazards. This is particularly true for Alpine areas, which are undergoing rapid changes due to climate change.

Recently, geomorphological mapping has increasingly relied on geodatabases integrated into GIS environments, gradually replacing traditional (i.e., manual) mapping and making the process more time-efficient and accurate [2]. Additionally, the growing availability of high-resolution airborne remote sensing data (e.g., digital elevation models from LiDAR surveys and digital orthophotos) enables the mapping of large areas and the precise delineation of landforms. The mapping process is further improved by GIS-integrated visualization tools, which enhance the interpretation and analysis of geomorphological features.

In this work, we present the new geomorphological database of the Adamello Brenta UGGp, an Alpine protected area which covers more than 1000 km^2 characterised by an impressive geodiversity and including part of the Dolomites UNESCO World Heritage Site (WH).

The project was aimed at providing a tool for promoting the geological heritage, supporting territorial planning, and developing educational and touristic activities. The project, funded by the UGGp, was carried out by the University of Pavia in collaboration with the University of Padova and with the support of the Autonomous Province of Trento (Geological Survey and Department for Protected Areas and Sustainable Development) and the UNESCO Dolomites Foundation.

Study area

The mapping activity was conducted in the whole area of the Adamello Brenta UGGp, which is in the southern sector of the Central European Alps (Figure 1). Elevation approximately ranges from about 260 m asl to over 3550 m asl, with more than 60% of the area above 1500 m asl.

The UGGp is characterized by two contrasting geological settings: i) the igneous rocks of the Adamello-Presanella Tertiary batholith (western sector) and ii) the Mesozoic sedimentary sequence of the Brenta Dolomites (eastern sector). The two sectors are divided by the Giudicarie line, which is part of the Periadriatic fault system of the Alps. The geological differences among the two sectors explain the remarkable richness of landforms that can be observed in the area, due to the different resistance of rocks to exogenic processes and different tectonic control. As a result, the two sectors exhibit considerably distinct large-scale geomorphological landscapes [3].

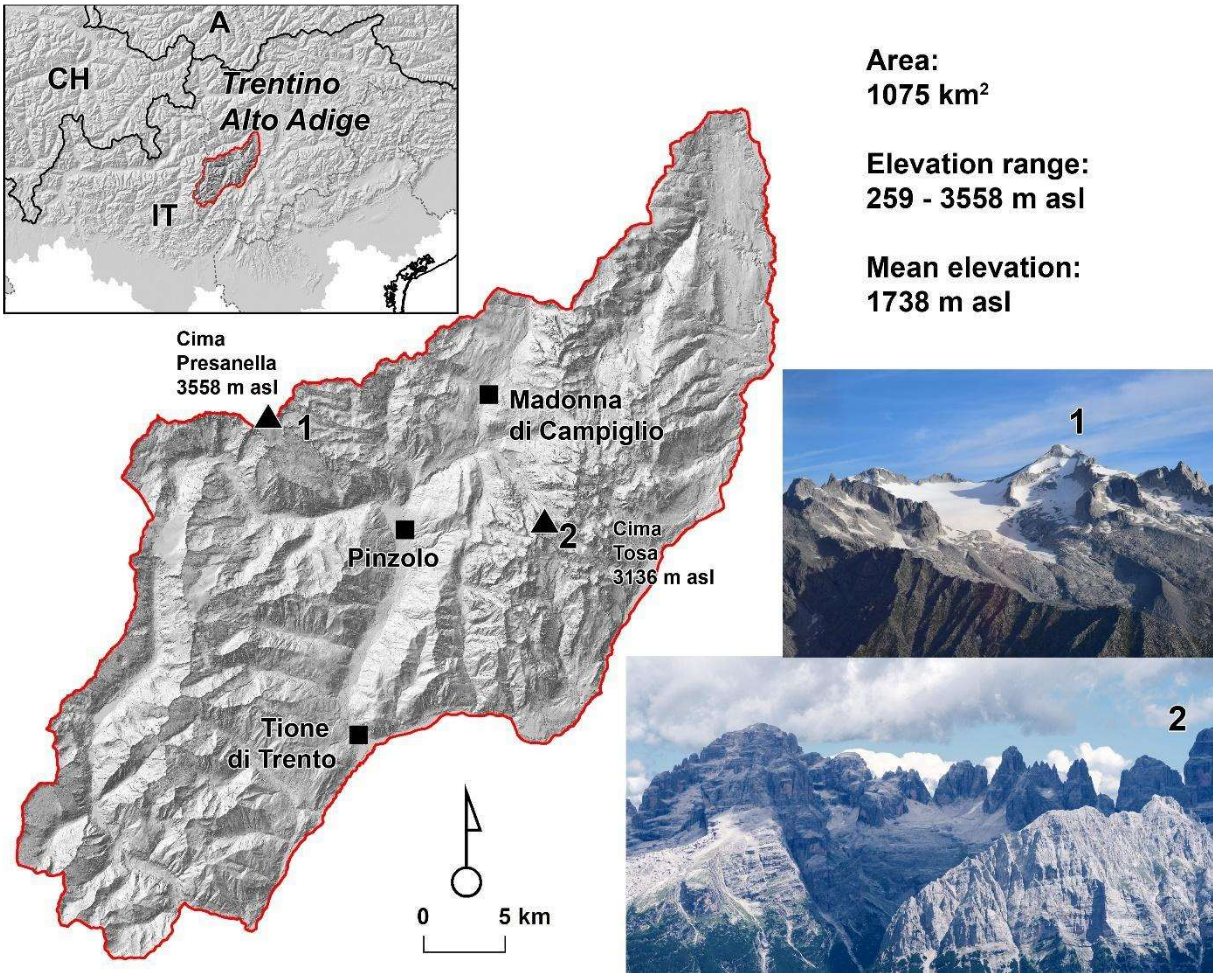

Figure 1. Geographic setting of the Adamello Brenta UNESCO Global Geopark. The two highest peaks in the western and eastern sectors of the Geopark are shown in the pictures.

Data and methods

Landforms were detected and mapped in a GIS environment using high-resolution airborne remote sensing data as background layers, such as shaded relief maps and digital orthophotos, covering the whole UGGp area. In particular, the shaded relief map was derived from a digital elevation model of 1 m ground resolution obtained from an airborne LiDAR survey carried out between 2006 and 2007. The orthophoto was obtained from flights carried out between 2014 and 2016 with a ground resolution of 0.2 m.

In addition, archival information and previously published maps and observations were used to check and validate the landform boundaries outlined from background layers. Moreover, we incorporated already existing datasets from previous projects and initiatives, provided by the Autonomous province of Trento (Geological Survey) through the dedicated geoportal as shapefiles or Web Map Services. These datasets included a rock glacier inventory acquired in 2010, the Little Ice Age glacial deposits and moraines, as well as a photo-interpreted glacier inventory acquired in 2006-2007 [4]. The bedrock lithology dataset was provided by the Geological Survey as part of the Official Italian Geological Cartography at 1:50,000 scale (CARG project). Field observations were conducted in specific areas to check and refine landforms geometry mapped from remotely sensed data.

In our project, we implemented the geomorphological geodatabase provided by ISPRA (*Istituto Superiore per la Ricerca Ambientale*) and AIGeo (*Associazione Italiana Geografia Fisica e Geomorfologia*), following the guidelines of the Official Geomorphological Map of Italy at 1:50,000 scale [5]. Our project represents the first application of the ISPRA-AIGeo geodatabase in an Alpine and topographically complex area.

This geodatabase distinguishes between natural and anthropic landforms, both defined as points, polylines or polygons. According to the genesis, the natural landforms are included in two main categories, i.e. endogenic and exogenic processes. Landforms resulting from exogenic processes are further divided into ten categories, most of which are present in the study area. Furthermore, each landform is described by multiple characteristics, which can be selected during the digitization phase from drop-down menus or added as text or numerical values. One of the most relevant types of information is the activity status of the landform, which can be "active" or "relict". Depending on the mapping scale, not all the features can be filled into the geodatabase. Moreover, some of this information would require field data or measurements that were not carried out in our work. Particularly, in this work landforms were mapped at a scale of approximately 1:10,000, which was considered the most suitable for producing geomorphological maps at a final scale of 1:25,000. The workflow used in the mapping process is shown in Figure 2.

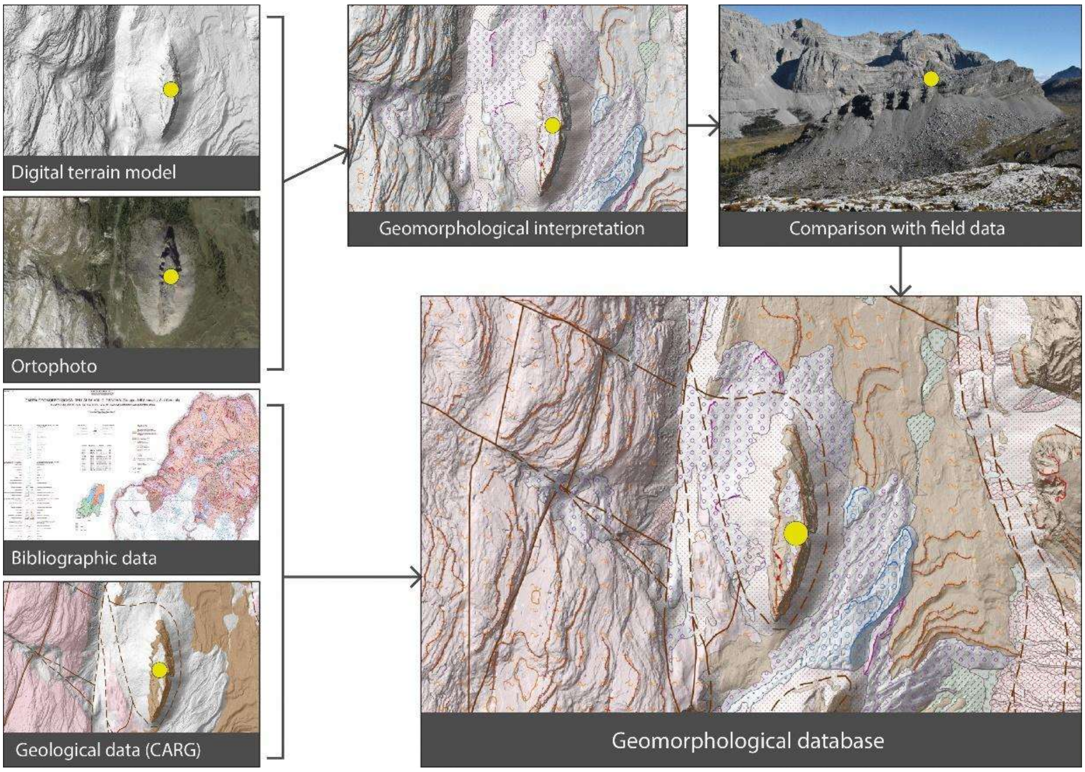

Figure 2. Workflow of the mapping process to obtain the final geomorphological database.

Main results

The geomorphological database of the Adamello Brenta UGGp indicates that approximately 45% of the area is covered by surface deposits, while around 51% consists of exposed bedrock (Figure 3). The remaining part is occupied by glaciers, glacierets and lakes.

The database includes more than 23,000 individual natural landforms, represented by more than 11,000 polylines and a similar number of polygons. The database includes over 500 anthropic landforms, represented by approximately 110 polylines and 400 polygons.

The landscape of the UGGp is characterised by glacial landforms, which cover 36% of the area. (Figure 3). However, lithological differences between the Adamello-Presanella and Brenta massifs explain the different patterns observed for the erosional and depositional glacial landforms. Particularly, results revealed the strong influence of karstic processes in the Brenta area (Figure 3). Landforms produced by gravitational processes are the most represented in the study area, covering more than 40%. Indeed, large areas of the Brenta massif are covered by rockslide deposits made up of large blocks. Fluvial and runoff processes affect approximately 12% of the area, primarily consisting of thick deposits at the bottom of the main valleys.

The geodatabase includes many landforms already inventoried by the UGGp as geosites of special importance and highlights additional landforms that are valuable for geoconservation and valorisation.

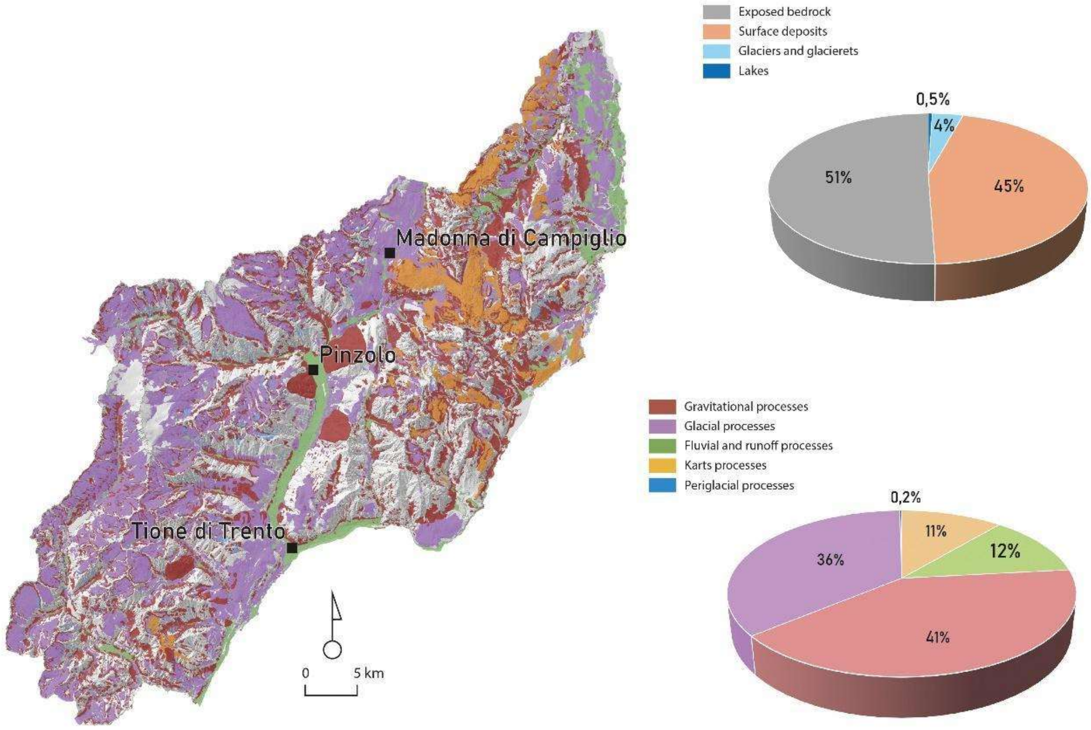

Figure 3. Map showing the distribution of the geomorphic processes in the study area. The upper graph shows the percentage of area covered by deposits, lakes and glaciers compared to the outcrop of bedrock lithology. The lower graph shows the coverage percentages of the different geomorphic processes.

Conclusions and outlook

The geomorphology of the Adamello-Brenta UNESCO UGGp has been mapped in GIS using a geodatabase developed according to the guidelines provided by ISPRA and AIGeo, in alignment with the Official Geomorphological Map of Italy at 1:50,000 scale. This geodatabase was tested in an Alpine area for the first time and serves as a fundamental tool for both increasing scientific knowledge about the territory and promoting its geoconservation. The geodatabase provides data that can be used for many purposes, including the production of geomorphological maps at various scales. Moreover, it can be used as a tool for protecting the geomorphological heritage included in the UGGp, as well as for promoting its educational and touristic value. As the geodatabase highlights several active processes and landforms, it can also serve as a valuable tool for territorial planning and management, especially in an Alpine area experiencing rapid changes due to climate warming.

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Geoscience popularisation in Geoparks: A Common Workflow for Digital Outcrop Modelling from the "3GEO" IGCP 714 Project

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Geodiversity has gained increasing attention, prompting geoscientists to advocate for its recognition to promote holistic nature conservation. UNESCO Global Geoparks (UGGps) have expanded globally, promoting geoheritage and contributing to geoconservation and sustainable tourism. In this framework, the IGCP 714 project, "3GEO – Geoclimbing & Geotrekking in Geoparks," launched in 2021, aims to use Geographical Information Technologies (GIT) – including GIS, remote sensing, Unmanned Aerial Vehicles (UAVs), and other geospatial tools - to enhance geoscience communication within UGGps [1]. However, there is still a significant need for a repeatable, accessible, low-cost, and effective workflow to integrate these digital technologies into geoscience communication effectively. This study developed a workflow for creating Digital Outcrop Models (DOMs) of geosites and geodiversity sites used for recreational climbing and trekking. Using technologies such as UAVs and Smartphones equipped with LiDAR sensors, the workflow generates DOMs that can be integrated into web-GIS applications and Virtual Reality experiences, offering interactive educational content [e.g., 2]. Four examples are described, illustrating the implementation of the DOM workflow from the outcrop scale (La Pedriza Granitic Batholith, Spain, and Etna Volcano Lava Tube, Italy) to the terrane scale (Organ Pipes Columnar Jointing, Australia, and Ossola Valley Metamorphic Uplift, Italy). The workflow is designed to produce DOMs for public and student engagement, demonstrating their potential for broader educational and geoconservation applications. Moreover, the workflow aims to build capacity among Geopark practitioners and researchers by improving techniques for creating content on geoheritage features and enhancing geoscience communication. For this, the workflow is designed to be repeatable by employing common and relatively low-cost GIT tools. We discuss the need for investment in capability, software, and hardware to equip Geopark practitioners with the skills required to implement this workflow. By applying this workflow to create DOMs of geoheritage features, we demonstrate its potential to enhance the appreciation of geodiversity, support education and research, and promote sustainable geotourism within UGGps.

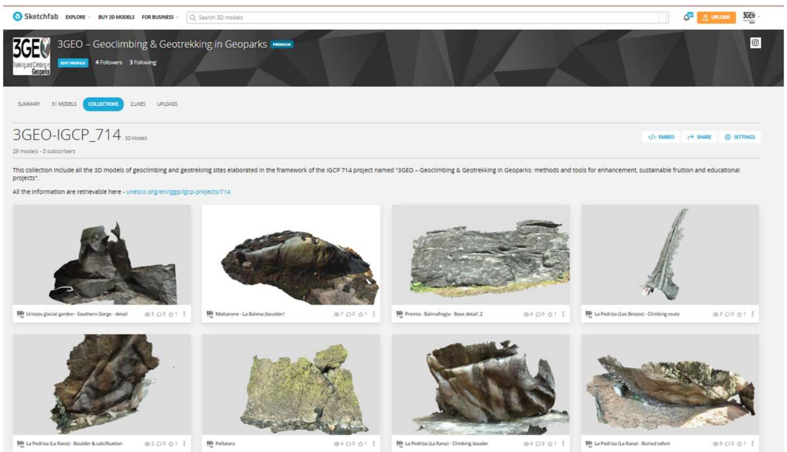

Figure 1. Preview of the 3GEO collection on Sketchfab with some of the models uploaded.

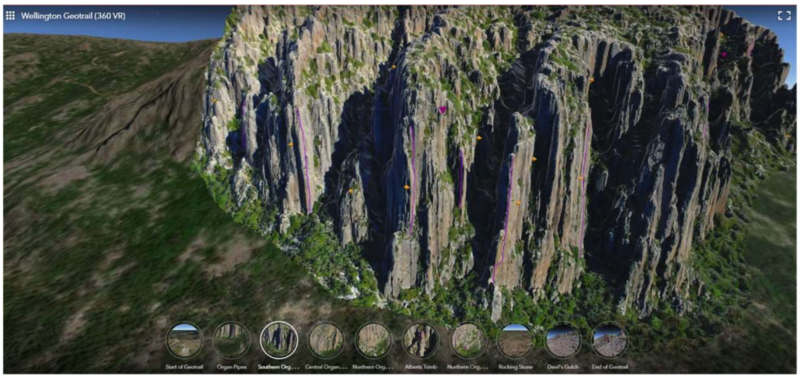

Figure 2. Southern Organ Pipes in the 360 VR.

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